INTERNAL COMBUSTION ENGINE MANUAL

STERLING

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PREFACE TO FOURTH EDITION.

The fourth edition of this volume, which marks its eighth year as a text book at the Naval Academy, has been completely rewritten, enlarged and brought up to date. The original sequence is still preserved, as it is believed the best for instruction of the uninitiated, viz:

(a) The subject of fuels is first treated fully, this being the fundamental element that governs design and operation. These fuels follow in a natural sequence which order is preserved when carburetion is taken up in Chapter V.

(b) The engine proper naturally divides itself into four systems: (1) fuel system, (2) ignition system, (3) cooling system, (4) lubrication system. These are treated in detail in the above order and in Chapter X the four systems assembled are illustrated by modern commercial engines.

A chapter has been added on the aeroplane engine and the five types, vertical, horizontal opposed, V-type, radial, and rotary are illustrated by up to date American engines.

The author wishes to acknowledge his thanks to Mr. J. G. O'Neill, chemist at the Naval Experiment Station, for his aid in enlarging the chapter on lubrication, and to the various manufacturers for their aid in preparing the text and cuts.

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CHAPTER I.

FUELS.

Selection.—The considerations governing the selection of a fuel in general are its accessibility, price, amount available, rate of combustion, and thermal value; it does not naturally follow that these are the only limitations which shall regulate the choice of a fuel for use in an internal combustion engine.

Fuel for use in an internal combustion engine must readily combine with air to form a combustible mixture of gas or vapor, must leave little or no solid residue after combustion, and must have certain thermo-chemical characteristics such as a proper rate of flame propagation, etc. It need not necessarily be of a very high calorific value, as will be shown later, but obviously this is desirable. The fuel is usually a compound of carbon and hydrogen, or a mixture of such compounds, found thus in nature or manufactured.

The General Classification of internal combustion engine fuels is:

1. The solid fuels.
2. The liquid fuels.
3. The gaseous fuels.

Solid fuels cannot be used in an internal combustion engine in their natural state, hence coal and other carbonaceous solids must be gasified to CO and H by partial combustion and volatilization to prepare them for such use. Although the Diesel engine was originally designed to use coal dust for fuel, and experiments have been made along this line, the idea was finally abandoned.

Solid fuels are converted into (a) *air gas,* (b) *water gas,* (c) *producer gas.*

Liquid fuels comprise (a) *distillates of petroleum* or *crude oil,* (b) *alcohol,* and (c) *benzol.*

The gaseous fuels consist of (a) *oil gas,* (b) *illuminating gas,* (c) *coke-oven gas,* (d) *blast-furnace gas,* (e) *natural gas,* and (f) *acetylene.*

Of all these fuels the most important marine fuels are the distillates of petroleum or crude oil.

1. Solid Fuels.

A, Air Gas; B, Water Gas.

Air Gas is entitled to no commercial consideration. It can be manufactured by the gasification of carbon by incomplete combustion to CO in a producer. The extremely low efficiency of such a process precludes its commercial use.

Water Gas.—If incandescent fuel is sprayed with water vapor, the H_2O is dissociated to H_2 and O, and the latter combines with the carbon in the fuel to form CO_2 or CO. H_2 is liberated. At temperatures below 1,250° F., CO_2 is formed, whereas, if the temperature be above 1,800° F., CO alone is formed. The production of water gas is accomplished in a producer. Its production is not highly efficient for the following reasons: Starting with a fuel in the incandescent state, the continued introduction of water vapor will cool the producer and when the temperature falls below 1,800° F. an excessive amount of CO_2 is formed. Unless this cooling action is counteracted the process will finally cease. When the temperature becomes too low the steam is shut off and the fuel is again brought to incandescence by blowing through with air. During this "blowing up" process gas of a low grade is formed. This is rarely utilized, and here we find the important loss which accounts for the low efficiency of production.

C. Producer Gas.

Producer Gas is formed by blowing a *mixture of water vapor and air* through a bed of incandescent fuel. Thus it is a combination of the two previous gases. Gas producers for the generation

of this gas have reached a high degree of efficiency and hold a large commercial field. They are used extensively in stationary gas-engine plants and in a few instances have been adapted to marine use. In practice, producer gas has a net thermal value of 150 to 180 B. t. u. per cubic foot.

Reactions.—The fuel in the producer may be divided into four zones. That zone nearest the hearth consists of ash. The next zone, called the combustion zone, is usually above 1,900° F. Here the carbon in the fuel is converted to CO_2. In the next zone, called the decomposition zone, the CO_2 from the second zone combines with the C in the fuel to form CO. Also the moisture in the blast combines with the carbon in the fuel to form CO and H_2. In the top zone, temperature about 1,300° F., to which fresh fuel is being constantly added, the volatile matter in the fuel is distilled off and mixes with the CO_2 and CO given off from the lower zones to form producer gas.

2. Liquid Fuels.

A. Petroleum and its Distillates.

By far the most important fuels for marine internal combustion engines are derived from petroleum. This important product is found in nearly every part of the globe. The United States, Mexico and Russia produce most of the petroleum at present. In this country the fields of Pennsylvania, Ohio, Oklahoma, Texas and California are the best producers.

Contrary to the popular idea, oil is not necessarily found in the vicinity of coal fields, but near salt deposits, the formation of salt and oil being apparently simultaneous. Although still open to dispute, it appears to be fairly well established that petroleum was formed by the decomposition of large masses of organic matter, probably of marine origin, and the subsequent spontaneous distillation of the hydrocarbons from such matter. Some few petroleums seem to be of vegetable origin.

As found in its natural state its composition varies with the field of supply, but in every case it consists of C and H with a

small amount of O and other impurities, the average for 13 fields being C 84 per cent, H 13.5 per cent, O and other impurities, such as sulphur, nitrogen and metallic salts, 2.5 per cent. The greatest variation from this in any one field is 2.5 per cent C. Its specific gravity (considering only those fields of commercial value) varies from .826 found in a Pennsylvania field to 0.956 found in the Baku region. A field in Kaduka, Russia, yields a crude oil with the low specific gravity of 0.65, and in Mexico an oil is obtained with the high specific gravity of 1.06.

Petroleum may be divided into two main groups, those having a paraffin base and those having an asphaltic base. The former yields a residue of solid hydrocarbons of the paraffin series, and the latter yields a residue rich in asphalt. Certain of the Mid-Continent crudes contain both paraffin and asphalt, so it is apparent that the two groups merge.

Refining.—Since the process of refining petroleum consists of many intricate and seldom divulged processes, it can be described only in the most general manner. Different oils require different treatment, and the process varies depending upon the product desired. The following is a brief description of refining a Pennsylvania paraffin base crude. It is carried on by fractional distillation, and, for convenience, this will be described in two stages.

First Stage.—Separation into groups by distillation. Crude oil is pumped into a cylindrical boiler, called a "crude still." When this is filled to a certain level fires are started underneath and vaporization and distillation commence. Distillation, as applied to hydrocarbon oil, is the separation of the more volatile portions from the less volatile portions by vaporization, and later condensing them by passing the hot vapors through a cooled tubular coil. Light hydrocarbons, such as gasoline, vaporize very readily, whereas heavy oils form practically no vapors at atmospheric pressure and temperature, therefore it is necessary to carry out fractionation in a closed vessel in order to accomplish complete separation of the different fractions. Since crude oil is a complex mixture of hydrocarbons, each of which has a different

boiling point, a different temperature is required for the vaporization of each compound. The lightest hydrocarbons pass over first at the lowest temperatures, and as the temperature is increased heavier and heavier hydrocarbons are vaporized.

Referring to Figure 1, the vapors formed are led through a pipe from the still and discharged into the base of an aerial condenser. From there they pass up through alternate boxes and air-cooled tubes, where products of different boiling points are simultaneously condensed and thus automatically separated into groups. The heaviest hydrocarbons (heavy lubricating distillate) condense upon striking the first nest of air-cooled tubes, and, dropping back into a collecting pan under this nest of tubes, is led by way of a water-cooled coil to the storage tank. The next heavier hydrocarbons (light lubricating distillate) condense in the second nest of tubes and are conducted by way of another collecting pan and pipe to a second tank. Gas-oil distillate and illuminating-oil distillate are similarly condensed in the third and fourth nests of tubes, and the naphthas and fixed gases pass over at the top in the form of vapor. The naphthas are condensed in the water-cooled coil in the collecting pipe and the very light hydrocarbons and fixed gases are carried over to a compressor (not shown), where the very light hydrocarbons are separated from the "fixed gases." The object of the water-cooled coils is to reduce the fractions below the fire point to prevent spontaneous combustion in the tanks. When the residue is reduced to about 15 per cent the fires are drawn and the residue, crude cylinder stock, is pumped from the still through cooling coils to a tank.

The steam connection shown in the still is used to allow steam to bubble through the crude oil when distilling for high-quality oils. Due to the mixture of oil and water vapors in fire and steam distillation, oil vapors pass over at lower temperatures than were fire used alone. The same results are obtained by placing the still under a partial vacuum during the process. It prevents the occurrence of "cracking."

Cracking.—Dry or destructive (cracking) distillation is re-

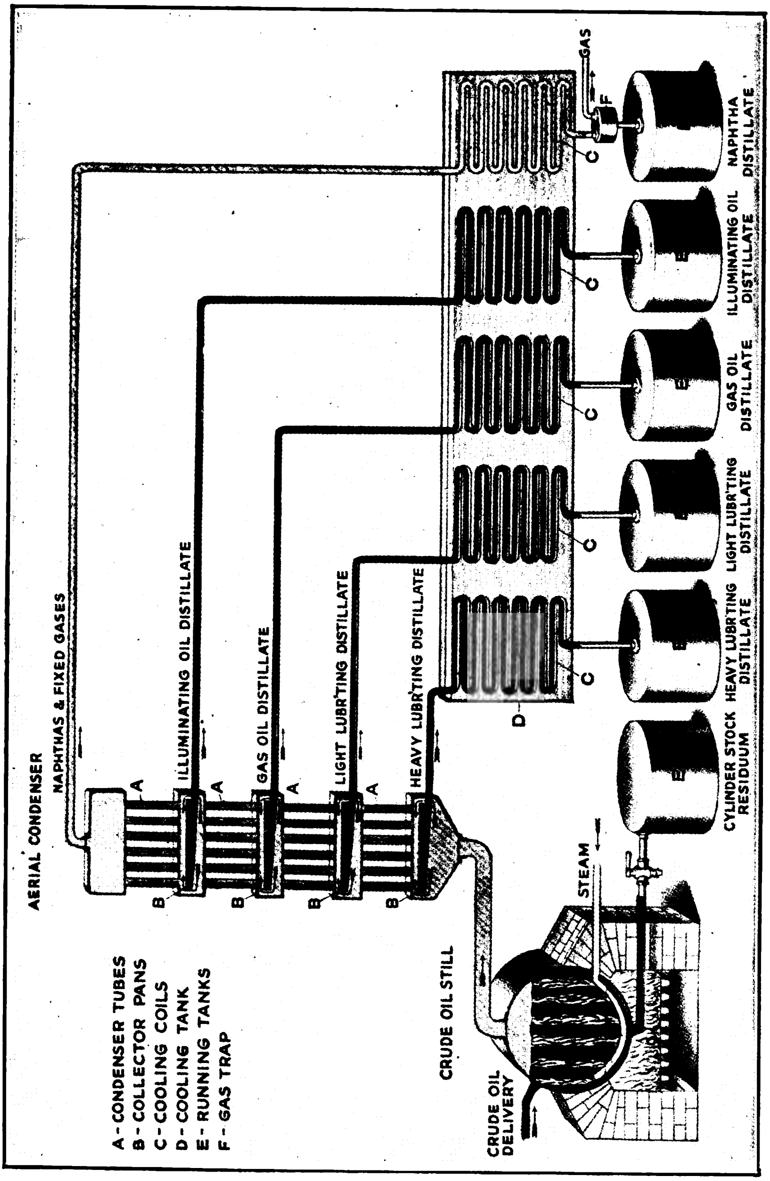


FIG. 1.—First Separation of Crude Petroleum into Groups by Distillation.

sorted to when a large yield of gasoline or kerosene is desired. It is best adapted to petroleum which is unfit for the manufacture of cylinder stocks. The petroleum is fire distilled, namely, distilled without the use of steam. Temperatures are carried higher than the normal boiling points of the desired fractions. Also the still is under more than normal pressure. The result is dissociation of the heavier constituents. The heavy vapors which condense in the top of the still fall back into the superheated oil and are partially decomposed. The resulting products are oils of lighter gravity than would be the case by steam distillation.

Second Stage.—Redistillation and finishing the fractions. In the first-stage distillation there is no sharp line of demarkation between the different fractions. Heavy constituents are carried over mechanically with the lighter products and the more volatile products are mixed with the heavier parts. To completely separate the fractions redistillation is necessary.

The naphtha distillate is divided, by redistillation in a steam still, into the various market grades of gasoline.

The illuminating-oil distillate is redistilled in a steam still to eliminate any contained crude naphtha, which is led to the crude naphtha tank, the finished product being kerosene.

The other distillates are treated in a similar manner. In the case of paraffin-base oils, the lubricating distillates go through a process to extract the paraffin wax.

Finishing.—During or after the redistillation operations the fractions must be chemically treated to remove impurities. The fraction is placed in an agitator, where it is treated with sulphuric acid, washed with water to remove free acid, and, neutralized with caustic soda, again washed, and the remaining water settled out. In the case of the heavier oils, steam coils in the settling tanks aid this settling process by temporarily reducing the viscosity of the oil. The final product is filtered through fuller's earth to remove color-bearing compounds and free carbon. The finishing process removes, or decomposes, aromatic compounds, acids, phenols, tarry products, sulphur and free carbon.

Temperatures at which the Fractions Distil.—If the process

were carried out in a laboratory to obtain the distillation temperatures of the different petroleum products the results would be somewhat as shown in the table below:

Temp. (Fahr.)	Distillate.	Per cent.	Specific gravity.*	Flash point.* (Fahr.)
Degrees.				
113–140	Petroleum ether	Trace.	.6	.....
140–160	Gasoline } commercial gasoline	2	.65	10
160–250	Benzine, naphtha } commercial gasoline	10	.70	14
250–350	Kerosene, light } commercial gasoline	10	.73	50
350	Kerosene, medium	35	.80	150
400	Kerosene, heavy	10	.89	270
482	Lubricating oil	10	.905	315
.....	Cylinder oil	5	.915	360
.....	Vaseline	2	.925	.....
.....	Residue	16	.....	.....
		100		

* Approximately mean values.

The nomenclature applied to petroleum products throughout the world is so varied as to become confusing, benzine, naphtha, gasoline and kerosene being used very indiscriminately. For simplicity we might divide petroleum products used as fuel in the internal combustion engine into (1) commercial gasoline and (2) kerosene and the heavier petroleum distillates.

1. Commercial Gasoline.

All figures relative to the boiling point, specific gravity, composition, etc., must be comparative, for naturally the product varies with the field of production of the original crude oil. Approximately the range of distillation temperatures for commercial gasoline is 115° to 350°. At the lower temperature gasoline is distilled off, then, as the temperature is increased, follow benzine, naphtha and light kerosene in the order named. Commercial gasoline may contain any or all of these fractions. Its specific gravity varies from 0.65 to 0.75, depending upon the proportions of C and H in its composition, and it weighs about 5.9 pounds per gallon. The analysis of an ordinary sample shows C 85 per cent, H 14.8 per cent, impurities (principally O) 0.2 per cent. Its net

thermal value varies with the analysis around 18,000 B. t. u. per pound.

The standard test for commercial gasoline is its specific gravity. Obviously this criterion is erroneous, as the ultimate value of gasoline as a fuel depends upon its volatility. For instance, a high-speed engine needs a light fuel, easily volatilized, while a heavy-duty, slow-speed motor can use a much heavier fuel. Were the entire supply of gasoline derived from one field, fractions obtained at the same temperatures would always have the same composition and hence the same specific gravity. But, as the world's supply is obtained from many fields in which the compositions vary, it is possible to obtain two gasolines of widely differing specific gravities, which will distil at the same temperature and which might be of equal value as fuels. The volatility of two gasolines being equal, the heavier is more efficient due to the presence of a higher percentage of carbon. This might appear paradoxical from the thermal view, but is based upon thermochemical considerations.

At present gasoline holds the internal combustion engine field as the most important of the petroleum products. To prepare gasoline for combustion it must be vaporized, and the ease with which this is accomplished gives it a decided advantage over all other liquid fuels. This fuel is vaporized or volatilized by passing air over or through the liquid, or by spraying the liquid into the air by force or suction. This process, called carburetion, will be treated in a later chapter.

2. Kerosene.

The next heavier distillate after gasoline is kerosene. This is given off at 350° F. to 400° F., and has a specific gravity ranging from 0.78 to 0.82. The composition of a test sample might run C 85.1 per cent, H 14.2 per cent, O 0.7 per cent. Its net thermal value is about 18,500 B. t. u., and its flash point is between 100° F. and 125° F. It is safer to handle and stow than gasoline and, being less volatile, does not deteriorate so rapidly.

It is not so widely used as an internal combustion engine fuel as is gasoline, for at ordinary temperatures it does not form an explosive mixture with air, and to render it a suitable combustible requires special treatment, such as introduction into a heated vaporizer, or spraying into a heated cylinder. This will be treated at length under carburetion. The introduction of carburetors which will handle either gasoline or kerosene may do much to bring it before the layman.

1. The Heavier Distillates.—Fuel oils have a specific gravity of 0.80 to 0.89, being of a thick consistency, have a high flash point and have a heating value of 17,000 to 19,000 B. t. u. This is the fuel used in what are known as oil engines. It must be sprayed into the hot cylinder or vaporized in a heated vaporizer. Heat is imperative for its conversion to vapor, as it will not form a combustible vapor at ordinary temperatures.

2. Crude Oil.—Crude oil is the same thing as petroleum and has been described under that head. It is used in some motors, notably the Diesel engine, by spraying it into the cylinder which is partially filled with heated highly compressed air, but when so used the lighter oils are distilled off ("topped") before using the crude. When crude oil is used without previous topping the lighter hydrocarbons are dissociated in the engine and cause carbon deposits.

B. Alcohol.

Although there are over twenty compounds known to the chemist as alcohols, the most important as a fuel is ethyl alcohol, expressed by the formula C_2H_5OH. Being a fixed compound, its characteristics cannot vary as in the case of petroleum products. Absolute alcohol, that is 100 per cent pure, has a specific gravity of 0.7946 at 15° C., and 1 gallon weighs 6.625 pounds. Its great affinity for water militates against the commercial article being very pure.

Some years ago Congress removed the revenue on alcohol if "denatured," and this action was expected to stimulate alcohol engine development. The results were discouraging. This denaturizing process consisted of adding to the ethyl spirit a fixed

amount of methyl or wood alcohol to render it undrinkable, and a small percentage of benzine to prevent the redistillation of the ethyl spirits. Congress prescribed the following formula: 100 volumes 90 per cent ethyl alcohol, 10 volumes 90 per cent methyl alcohol, and ½ volume approved benzine. Benzine raises the thermal value of the mixture. One of the denaturizing agents required by the laws of some countries is benzol. This benefits the fuel by neutralizing the formation of acetic acid in the cylinder during combustion.

As noted above, alcohol is rarely found free from water and is therefore designated by its percentage of purity, thus, "90 per cent alcohol" indicates the presence of 10 per cent water. Pure alcohol has a thermal value of about 11,600 B. t. u., and this value is reduced approximately 150 B. t. u. for each per cent of water present. From this it might be erroneously concluded that its thermal efficiency as an internal combustoin engine fuel is lower than that of gasoline. On the contrary, its thermal efficiency is higher, as alcohol can be more highly compressed, and the dissociation of its contained water seems to aid the expansion stroke. If equal weights of gasoline and alcohol are completely burned in two motors, the latter will require less air than the former, and consequently the heat losses in the exhaust gases are less per pound of fuel in the alcohol motor.

Alcohol is less volatile than gasoline and is easier to handle than kerosene. It requires a special form of vaporizer, for it will not form a combustible mixture with air at ordinary temperatures. Heat is employed to aid in its vaporization, as will be shown under carburetion. A mixture of equal weights of alcohol and gasoline forms a good fuel.

C. Benzol.

Benzol, C_6H_6, is a hydrocarbon by-product recovered from the coke oven, and when distilled pure is a white liquid of 0.88 specific gravity at 59° F., with a net thermal value of about 17,300 B. t. u. It can be used in gasoline motors either in its natural state or

mixed with gasoline. As dyestuff and explosive bases are manufactured from benzol, its use as a fuel is precluded in the present crisis, but there is no doubt that it will take its legitimate place as a motor fuel after the war.

3. The Gaseous Fuels.

A. Oil Gas.

Oil gas is generated by vaporizing crude oil by one of two distinct methods, (1) the Pintsch method, and (2) the Lowe process. At present it is used more extensively as an illuminating gas than as a gas-engine fuel. It is largely employed for municipal lighting.

1. *By the Pintsch method* oil is led through a retort which is externally heated. A thin film of oil is kept in contact with the heated surface and is thus volatilized into a fixed gas. It varies considerably in composition, depending upon the original crude oil, being a mixture of hydrocarbons and free hydrogen. Gülder gives one formula as follows: C_2H_4, 17.4 per cent; CH_4, 58.3 per cent; H, 24.3 per cent; by volume.

2. *The Lowe process* employs a fire-brick lined furnace containing a checker-board form of grating made of fire brick. This grating is heated to a very high temperature by an oil-air blast. When the desired temperature is reached the blast is shut off and the chimney is closed. An intimate mixture of crude oil and superheated steam is now sprayed on to the hot grate and (air being excluded) this mixture is volatilized into an oil-water gas. The grate must be reheated periodically. The analogy to the manufacture of water gas is apparent. In addition to the hydrocarbons generated by the Pintsch method we have N, O and CO in small quantities in gas made by this method.

The process of generation being completed by either method, the resulting product is washed, scrubbed and purified by the usual method. Although the heating value per cubic foot of Pintsch gas is nearly 40 per cent greater than that made by the Lowe

process, if based upon fuel consumption required for manufacture, their thermal values are nearly equal.

B. Illuminating Gas.

This gas is a mixture of H, CO, CH_4 and other heavy hydrocarbons, O, N and CO, given up by bituminous coal when it is heated in a retort, air being excluded. The residue is coke, tar and ammonia liquor. Part of this coke can be utilized to heat the retort. One ton of coal will give off about 10,000 cubic feet of gas. Its composition necessarily varies widely, dependent upon the coal used and the temperature of volatilization. Its heating value, which varies with the composition, is about 600 B. t. u. per cubic foot.

C. Coke-Oven Gas.

Coke is produced by distilling off the volatile matter from coal in a coke oven from which air is excluded. The volatile matter, coke-oven gas, contains hydrocarbons, hydrogen and traces of CO, N and O. Tar, ammonia liquor and benzol are also present, and these are removed from the gas by washing, forming valuable by-products. The gas is used extensively under boilers and in metallurgical furnaces, and is a suitable fuel for large gas engines. Its thermal value varies from 460 to 500 B. t. u. per cubic foot.

D. Blast-Furnace Gas.

The production of pig iron is accompanied by the partial combustion of coke. The gas evolved during this process can, after suitable purifying, be used as a gas-engine fuel. It contains about 5 per cent H, 27 per cent CO, very small quantities of CH_4 and O, considerable CO_2 and about 60 per cent N. Hence its heating value is very low, ranging from 86 to 100 B. t. u. per cubic foot. Its use is limited to iron-making districts. Heavy-duty motors, of large capacity, are manufactured especially to utilize this heretofore waste product. Blast-furnace gas requires a high compression to facilitate ignition and combustion.

E. Natural Gas.

Natural gas is found in or near all oil fields. It is obviously a volatile product of oil in a natural state. Many towns light, heat and receive power from this source. Its use as a gas-engine fuel has been developed more rapidly in this country than abroad. Its composition varies with the well, and even the same well may give different results at different times. Hydrogen and hydrocarbons are its principal constituents. The continued supply is rather uncertain in any given district. Excessive H might cause pre-ignition, but, when not too high in H, it is an excellent gas-engine fuel. Notwithstanding the fact that it has a very high heat value, it does not develop as much power as gasoline vapor.

F. Acetylene.

Acetylene, C_2H_2, has been used experimentally in internal combustion engines. Its temperature of ignition is low and, since it will ignite spontaneously at low pressures, it is unsuitable for use in a high-compression engine. It has a high heat value of about 18,000 B. t. u. per pound, and, having a high temperature of combustion and a high rate of flame propagation, the energy derived from it is high. Its cost of production precludes its competition with other fuels at present. Liquid acetylene has been suggested as a possible fuel, but, as yet, extensive experiments have not been conducted along this line.

CHAPTER II.

GENERAL.

An internal combustion engine, as the name implies, is one in which, in contradistinction to the steam engine, combustion of the fuel takes place in the cylinder itself. A steam engine cannot run without a separate unit, the boiler, for the consumption of fuel and generation of steam, the medium of motive power. Hence in the gas engine vernacular it is called an *external combustion engine.* On the other hand, fuel is fed directly to the cylinder of an internal combustion engine, ignited therein, and the resulting explosion acting on the piston furnishes the motive power.

Progressive Combustion.—The internal combustion engine is commonly, though erroneously, called an explosion engine. The action which takes place, and which appears to be an explosion, is in reality a progressive combustion and subsequent expansion of the products of combustion. Some oil engines actually carry the combustion through a considerable part of the stroke. Although the expansion line of an indicator card is necessarily of interest to the manufacturer, the ratio of expansion presents no problem, for the internal combustion engine has no adjustable cut-off, and therefore the ratio of expansion is fixed for a given engine by the clearance space and the space swept by the piston.

The problem of expansion is replaced by questions of rate of combustion, rate of flame propagation, quantity and quality of fuel, and, most important of all, *compression.*

Compression.—The question of compression will be treated at length later, but a word here is necessary to what follows: when a fuel, such as gas, is admitted to the cylinder of an engine, a certain quantity of air is admitted at the same time to furnish the necessary oxygen for combustion. Before ignition this "*mixture,*" as it is called, is *compressed* into a small space

called the "*clearance space.*" This compression serves to ***mix the particles of air and fuel*** more intimately and to ***raise the temperature*** of the mixture. The resultant compressed mixture will ***ignite with more certainty*** and will ***burn more evenly*** than a rarer and colder mixture.

There are four essential systems to every engine, and these are treated at length in subsequent chapters. They are: (1) fuel system; (2) ignition system; (3) cooling system; and (4) oiling system.

Fuel System.—This consists of a fuel tank, a strainer for liquid fuels, the carburetor, atomizer, or other agent for converting the fuel to a combustible vapor, and the exhaust, which usually terminates in a muffler. In the case of liquid fuels it is necessary to volatilize and mix them with air before they can be ignited in the cylinder. Fig. 2 illustrates an ordinary gasoline fuel system.

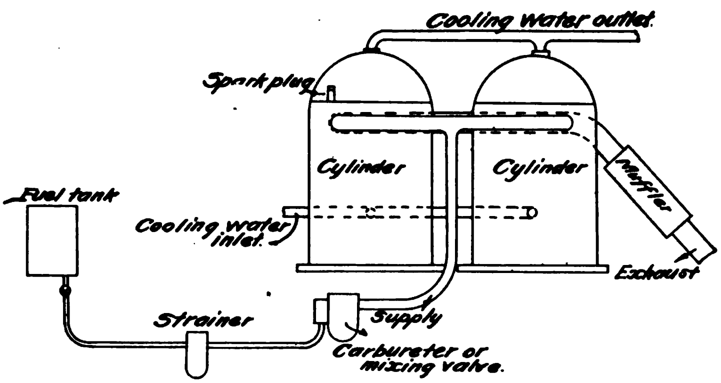


FIG. 2.—Schematic Plan of Marine Gasoline Engine Plant.

Ignition System.—If the ignition is electrical, this system consists of a source of current supply, wiring, and a means of causing a spark to leap a gap, thus forming an arc in the presence of the fuel in the cylinder. The spark thus created ignites the mixture. If the system is not electrical, then it consists of an apparatus designed to bring the combustible mixture in contact with a sur-

face hot enough to ignite it. This is treated in detail under the chapter on ignition.

Cooling System.—This consists of artificial means for keeping the cylinder from overheating. It is discussed at length later.

Lubricating System.—This is more complex than in the case of the steam engine, as it is necessary to include in the system means of lubricating the insides of the cylinder walls. It is discussed in a later chapter under the subdivisions, ***kind of oil*** and *lubricating systems.*

The Four Requisites.—As early as 1832 Beau de Rochas announced the four requisites for economical and efficient working of internal combustion engines, and, with one exception, these are undisputed today. They are:

1. The maximum cylinder volume with the minimum cooling surface.
2. The maximum rate of expansion, hence, high speed.
3. The greatest possible pressure at the beginning of expansion, hence, high compression.
4. The greatest possible expansion, hence, long stroke.

Short and Long Stroke.—Much discussion has arisen on the merits of the long or short stroke motor. The long stroke gives a greater expansion, but it also increases the duration of contact of the gases with the cylinder walls. This increases the radiation losses. The short stroke decreases the expansion, but it also decreases the radiation losses. This point is discussed later.

COMPARISON OF INTERNAL COMBUSTION AND STEAM ENGINES.

Advantages of the Internal Combustion Engine.—1. *Fuel Consumption.*—The principal advantage of the internal combustion engine plant over the steam plant is in thermal efficiency. The steam reciprocating engine plant attains an overall efficiency of from 5 per cent to 10 per cent, and the overall efficiency of internal combustion engine plants range from 17 per cent to 30 per cent. Fig. 3 illustrates the principal heat losses in the two

plants. The sister ships, *Kanawha* and *Maumee,* afford an excellent opportunity for comparing these two types of motive machinery. They are employed on similar duty, use the same fuel, and have practically the same horse power. At 12.5 knots the *Maumee,* with Neurnberg engines, burns about .5 pound of oil per shaft horse-power hour, and the *Kanawha,* with reciprocating steam engines, consumes about 1.4 pounds of oil per shaft horse-power hour.

2. *The cruising radius* of a vessel propelled by oil engines is increased due to decreased fuel consumption.

3. *Radiation or leakage losses* in boiler and piping are absent in an internal combustion engine plant, also there are no "stand by" losses.

4. *Handling.*—The internal combustion engine is easier to start and stop, warming up not being necessary; the engine is ready for full load after a few revolutions.

5. *Working force.*—In the internal combustion engine plant labor is reduced and fewer attendants are needed.

6. *High pressures* in the internal combustion engine are present only in the cylinders, which are the only parts necessary to be designed for high pressures.

7. *Weight and space.*—In small units, such as launch installations, the internal combustion engine plant is simpler, more compact, and lighter than the steam plant, due to the absence of a boiler. In large marine installations there is little difference in the weight and space required for the two types. Reverting to the *Maumee* (oil engines) and *Kanawha* (steam plant), the former is heavier and more costly than the latter, and actually requires slightly more floor space.

Disadvantages of the Internal Combustion Engine.—1. *Waste of heat in exhaust gases.*—Up to date the internal combustion engine has not been successfully compounded, and the utilization of the heat in the exhaust gases has long been an unsolved problem. Exhaustive experiments have been conducted, and it can be stated on reliable authority that this problem has reached a successful solution, but results cannot be published at this time.

2. *Waste of heat in cooling water.*—Whereas the steam engine cylinder is maintained at as high a temperature as possible to prevent liquefaction, this does not hold in an internal combustion engine. A large amount of heat must be absorbed by the cooling water to prevent overheating and consequent injury to the cylinder, and the heat thus carried off is a total loss. This problem was solved at the same time that the heat waste in the gases was investigated, and these results must also be suppressed for the present.

3. *Reliability.*—The internal combustion engine, until recent years, has not been as uniform in its impulse and speed as the steam engine and has not been considered as reliable. The latter has been due in part to ignorance on the part of operators, and it is now safe to assume that a well designed internal combustion engine is as reliable as a steam engine. Developments in governing have given such uniform speed that alternating current generators in parallel are driven by gas engines, and marine oil engine plants are in operation that leave little to be desired.

Summary.—From the foregoing balance of advantages in favor of the internal combustion engine, and from its remarkable overall efficiency, it must not be concluded that this type will ultimately supplant the steam engine and turbine. In a coking region or at a blast furnace plant, where a fuel supply is obtained from an otherwise waste product, there can be no question of its supremacy, but for marine use there have been several inherent difficulties to overcome.

Probably the most important of these was deterioration due to metallic disintegration of cylinder walls from severe vibration in the presence of intense heat. Also the question of expansion of the various engine parts, and the inability to obtain castings that will stand up under the severe work, have so far limited the size of cylinders, and hence the horse-power per cylinder. In view of the progress made in solving these metallurgical and design problems during the past five years, it is safe to predict that the internal combustion engine may be developed to very large sizes in the not distant future.

The ideal condition of an impulse per cylinder per stroke, which is present in the steam engine, is not attained in the internal combustion engine except in one case, that of the double acting tandem engine, which cannot be used in all kinds of work. Only one impulse is received for each two or four strokes in a single cylinder engine, and the engine must be multicylinder to get a continuous impulse. Six cylinders is the least number that will furnish an overlapping impulse if the engine be four cycle.

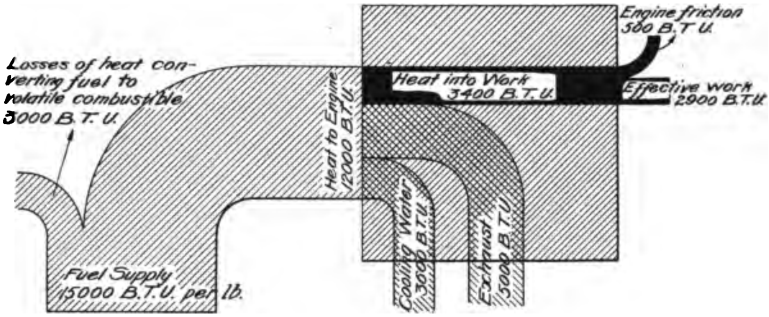
Heat Balance.—A table accounting for the heat furnished to an internal combustion engine is called the heat balance. From the diagram, Fig. 3, such a heat balance might be constructed. Generally the heat is accounted for under four items:

1. Heat of indicated work.
2. Heat loss to circulating water.
3. Heat lost in exhaust gases.
4. Heat of radiation, conduction, etc.

Such a balance for the engine under consideration would be:

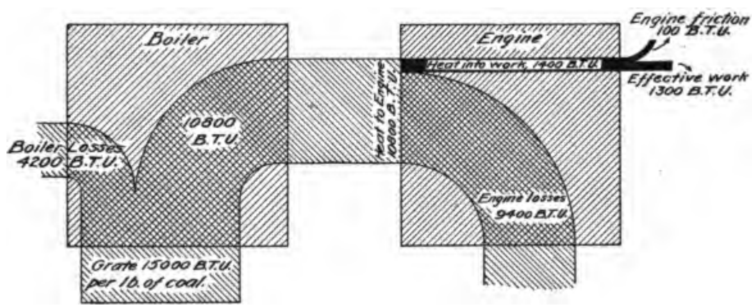
Heat converted into mechanical energy....	23.0%
Heat loss to circulating water...........	24.0%
Heat lost in exhaust gases...............	33.0%
Heat lost by radiation, conduction, etc....	20.0%
	100.0%

Items one and two can be determined accurately. The determination of item three is difficult and involves the weight of the exhaust gases and their specific heats at the temperature of the exhaust. Item four is the difference between the heat supplied and the sum of the other three items. Sometimes the heat balance is made up of three parts by combining items three and four.



Internal Combustion Engine Plant.
Diagram of Heat Losses per lb. of Fuel.

Overall Efficiency $\frac{2900}{15000} = 19.3$ per cent.



Steam Reciprocating Engine Plant.
Diagram of Heat Losses per lb. of Fuel.

Overall Efficiency $\frac{1300}{15000} = 8.7$ per cent.

FIG. 3.—Distribution of Heat Energy in Steam and Internal Combustion Engine Plants.

Development.—The rapid strides in the development of the internal combustion engine are due in a large measure to the demands of pleasure in addition to the needs of industry. The automobile industry has developed the high-speed motor to a very high state of efficiency. The aeroplane was made possible by the gasoline engine, all the other problems of human flight having been solved years before suitable motive power was available. Military necessity has caused an astoundingly rapid development of the high-speed motor both in size and efficiency under varying conditions. On the other hand, the industrial world was not behind in developing the slow-speed, heavy-duty motor, and we now find internal combustion engines employed for every conceivable duty from aeroplane propulsion to furnishing the motive power for agricultural machinery. Tractors are fast supplanting the horse.

For marine use, gasoline and oil engines have proved their efficiency in small units, such as launches, submarine chasers, etc., and recent internal combustion engine installations on large ships have been attended with complete success. The largest oil engined motor ship thus far built in the United States is the twin-screw Naval collier *Maumee,* of 14,500 tons displacement, propelled by two single-acting two-cycle Diesel engines of 2,500 shaft horse-power each.

CHAPTER III.

CONSTRUCTION.

The subject of internal combustion engine construction will have to be treated in a very general manner because of the variety of forms of all the parts found in different types. Naturally the design of engine depends upon the service it is intended to perform, thus, the aeroplane engine is constructed in this country to weigh as little as two pounds per horse-power, whereas engines for marine use weigh from 45 to 60 pounds per horse-power for launches, and as high as 350 pounds per horse-power for large marine plants. With the many types existing it is only possible to give a few general forms of parts.

Cylinder.—Cylinders may be cast singly or *en bloc*; that is, in a multicylinder engine each cylinder may be cast as a separate unit or two or more may be cast in one piece. They are generally classified as (1) water cooled and (2) air cooled, depending upon the system adopted to prevent overheating of the cylinder. Fig. 4 shows a water cooled cylinder with the annular space in which to circulate water. Fig. 5 shows an air cooled cylinder. The ribs

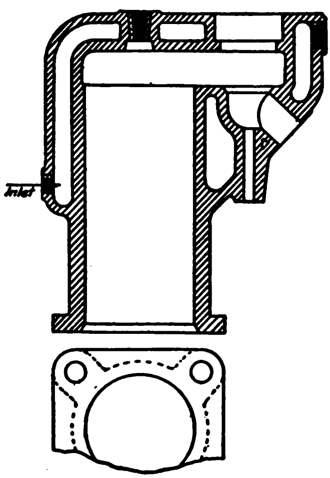


FIG. 4.—Water Cooled, Four Cycle Cylinder.

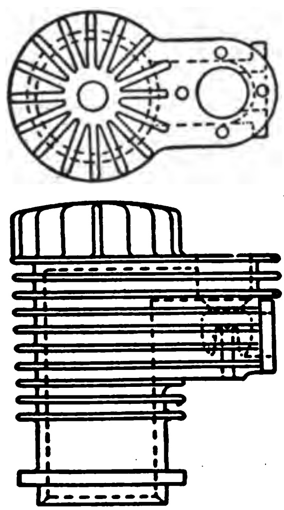


FIG. 5.—Air Cooled, Four Cycle Cylinder.

cast on the outside of this cylinder increase the radiating surface of the cylinder and thus serve the same purpose as the circulating water in the other type. It should be noted that the annular space and the ribs do not extend the full length of the cylinder, but only cover the upper part. They only extend a little below the compression space, which is the hottest part of the cylinder. Fig. 6 shows a water cooled cylinder with a copper water jacket fastened and caulked to the cylinder. The corrugations shown allow for the unequal expansion of the copper of the jacket and the iron of which the cylinder is cast. This construction is the more expensive of the two and is only used in automobile and aeroplane

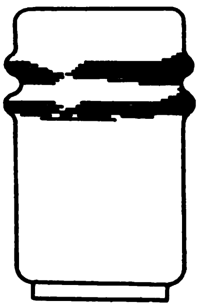


FIG. 6.—Copper Jacketed Cylinder.

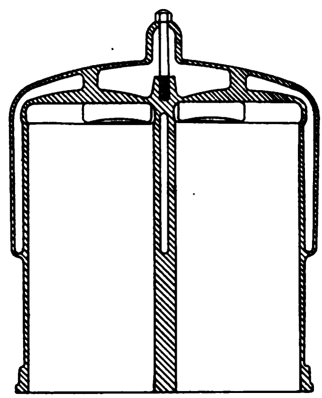


FIG. 7.—Pair of Cylinders Cast *en bloc.*

engines. Copper water jackets may be electrically deposited as follows: After the cylinder is machine finished a wax mold is built on its outer surface to conform to the shape of the water jacket. This wax mold is coated with a graphite conducting film and the whole placed in a copper plating bath. When copper is deposited to the requisite thickness the cylinder is removed from the bath, the wax mold is melted out by low heat, and the space formerly occupied by the wax becomes the water jacket space. Fig. 7 illustrates a pair of cylinders cast *en bloc.*

Cylinders are made of close grain, gray cast iron, hardness being the essential requisite. The previous four illustrations

portray the four cycle type engine; Fig. 8 shows the general type of two cycle cylinder without valves; the piston passing over the port openings acts as a valve. The cylinders are counterbored at the ends of the stroke. This prevents the formation by the piston ring of a collar at each end of its travel.

Piston.—The majority of internal combustion engines are single acting, receiving the impulse on only one end of the piston. The impulse is much more sudden than in the case of the steam engine, and if the piston were constructed disc shaped, as in the steam engine, there would be a tendency to cant or dish on the explosion stroke. For this reason and for the purpose of aiding

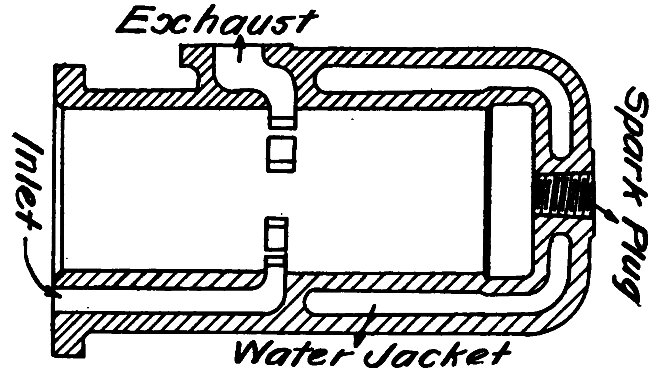


Fig. 8.—Two Cycle Water Cooled Cylinder.

packing, cooling and guiding generally, the piston is made long and hollow, the length for a good four cycle, high-speed design being about one and one-half times the diameter. In this type the length precludes the necessity for connecting rod and guides. The piston is tapered, the explosion end being slightly smaller, say .001 of the diameter, than the opposite end. The reason for this is that the explosion end, being in contact with the hot gases, when running, will expand more than the other end. It is fitted with eccentric rings, usually four, which spring into grooves shown in Fig. 9, the lowest ring acting as an oil ring. Fig. 10 shows a piston with rings, connecting rod and bearings, all assembled. Heavy duty and double acting engines have different types of

pistons, some being of such a form as to require piston rods, connecting rods and guides. These are illustrated in Chapter X.

Figs. 11 and 12 are two types of piston heads for two cycle engines. The dished head, Fig. 11, and the web cast on top of the piston, Fig. 12, serve to deflect the incoming gases and thus aid in scavenging the cylinder.

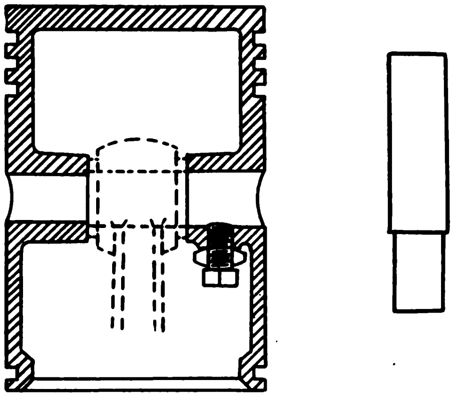


FIG. 9.—Piston, Showing Method of Securing Connecting Rod.

Connecting Rod and Wrist Pin.—In all engines, except the large stationary ones, the piston rod is absent, the piston motion being communicated to the crank direct by the "connecting rod." At the piston end the rod is connected to the "wrist pin." There are two ways of forming this bearing; first—the one most com-

FIG. 10.—Piston with Rings, Connecting Rod and Bearings Assembled.

monly used—the wrist pin is locked fast to the piston, the rod working on it; and second, the rod is locked fast to the wrist pin and the pin works in the piston as a bearing. Fig. 9 illustrates

the first method, a set screw and lock nut being shown in place. Rods are forged of drop forged steel, the heavy stationary engines having rods of rectangular section and the marine and lighter engines having an "I" section rod.

Valves.—The most common and best developed valve at present is the disc, poppet valve shown in Fig. 13. Drop forged valves answer the purpose for all but the heavier engines, which require valves cast in one piece. The best material must be used in valves, especially the exhaust, as they are subject to the intense

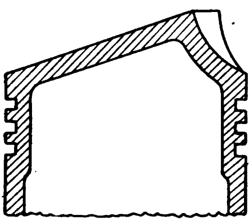


FIG. 11.

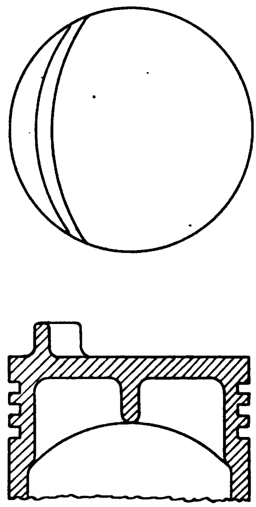


FIG. 12.

Two Cycle Piston Heads.

heat of explosion, and the exhaust valves receive the full erosive effect of the fast moving, hot exhaust. The smaller valves have a slot in the head to fit a screw-driver or tool for regrinding to the seat.

The requirements for an efficient valve are: (1) it must be gas tight without excessive friction; (2) the opening and closure must be instantaneous; (3) it must be accessible for cleaning, grinding, etc.; (4) the gases must not be wire drawn.

Location of Valves.—Both admission and exhaust valves may be located in the breech end on the same side of the cylinder

(called "L" type), see Fig. 4; or on opposite sides of the cylinder (called "T" type), see Fig. 69; or one or both may be placed in the cylinder or breech end tops (called "valve-in-head" type), see Fig. 20.

The exhaust valve is generally actuated by cam gear situated on a camshaft that is geared to the main shaft. This is also the better method for actuating the admission valve, although some engines are fitted with spring loaded admission valves that lift automatically on the suction stroke. In some designs a rod and rocking lever, actuated by a cam, opens alternately both admission and exhaust valves of the same cylinder. The Curtis engine and many motorcycle engines are of this type.

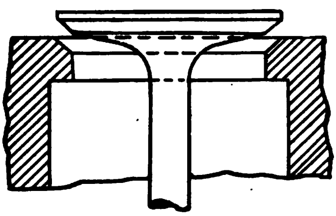


FIG. 13.—Conical Disc, Poppet Valve.

There are a variety of novel valves, such as rotating valves, that have not received general recognition. The Knight motor (Chapter X) has two reciprocating sleeves between the piston and the cylinder. These sleeves contain openings that cover and uncover the port openings at the proper points of the cycle and thus act alternately as admission and exhaust valve. The larger exhaust valves are hollow to permit circulation of water for cooling the valve.

Push Rods.—Interposed between the valve stem and the cam on the camshaft is a push rod, Fig. 14. As seen in Fig. 18, these are carried in guides that fasten to the engine base. In most designs a hard steel roller that bears on the cam is fitted on the lower end to give minimum friction. For high speed engines the top of the push rod has an adjustable screw that bears on the

valve stem so that wear on the end of the rod can be compensated; this tends toward quiet running, and aids valve timing.

Fly-Wheel.—On account of the intermittent impulse given an internal combustion engine shaft, all engines having six or less *working* cylinders require a fly-wheel. By its inertia it tends to give a uniform rotation to the shaft in spite of the non-uniform crank effort. Obviously, the relative size of fly-wheel required increases with the decrease in the number of working cylinders.

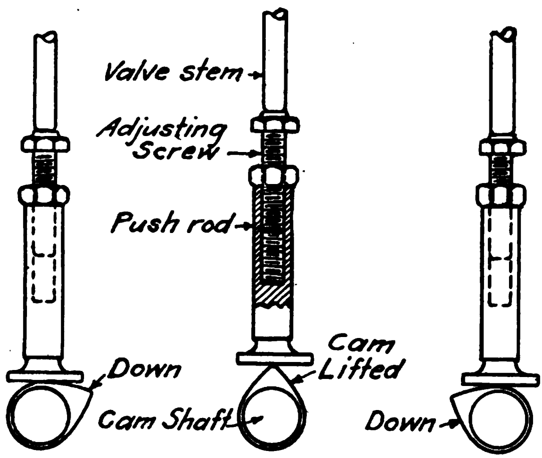


FIG. 14.—Push Rod.

The same features govern fly-wheel design whether for internal combustion or other engines, except that more care must be taken in the balance of those used in this particular field.

Balancing the Crank Arm.—Single-throw cranks for high-speed engines are provided with balance weights to balance the weight of the crank pin, web, and that part of the connecting rod that is regarded as rotative. These weights are generally located on both crank webs, and must be securely fastened, because any play between them and the web would rapidly increase from the engine vibration and would cause serious trouble. The counter-weights for small shafting are made integral with the crank web.

Muffler.—For quiet operation the muffler is an essential part of the exhaust system. Exhausting into the atmosphere at the normal exhaust pressure causes a sharp, disagreeable noise. This is so annoying that many municipalities have passed ordinances requiring that all internal combustion engines be fitted with mufflers.

A muffler is merely an enlargement near the end of the exhaust line to allow a gradual expansion of the exhaust gases to the atmospheric pressure. Though there are a variety of forms, the principle is the same in all. Cast iron is generally used in construction, as this best resists the corrosive effects of the hot gases.

Some mufflers are fitted with baffles, and in this case care must be taken in the design to prevent a back pressure in the exhaust. A properly designed muffler will reduce the pressure at the muffler exit without reducing the speed of the exhaust from the engine to the muffler. As long as this speed is maintained no back pressure will result. In stationary plants water spray is sometimes injected into the muffler. This is standard marine practice.

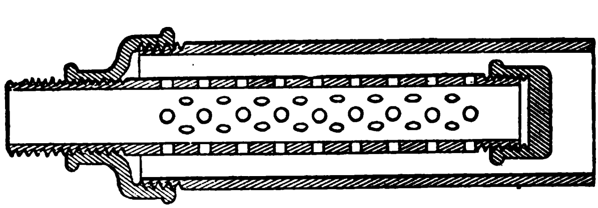


Fig. 15.—Gas Pipe Muffler.

The gas pipe muffler, Fig. 15, illustrates the muffler principle. It consists of a perforated exhaust nozzle within a larger open end pipe. The exhaust puffs pass through the perforations and expand into the larger pipe, passing out at the end at a more even pressure.

The marine type muffler, Fig. 16, is a water cooled type. The cooling water entering through the top inlet, flows over the cooling plate on which the entering gases impinge. The gases are saturated with water vapor, lowering their temperature and re-

ducing their volume. The saturated gases strike the mixing plate and flow into the expansion chamber through openings at the mixing plate edge. They leave the muffler through the perforated silencing sleeve at a steady pressure.

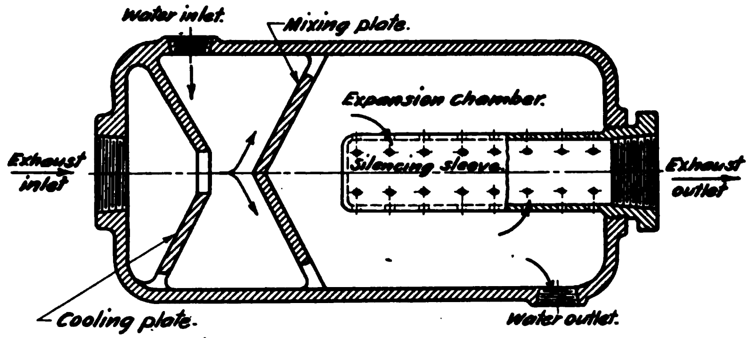


Fig. 16. Marine Type Muffler.

The ejector muffler, Fig. 17, is designed, as its name implies, on the principle of an ejector. It consists of three expansion chambers which are formed by conical baffle plates, perforated top and bottom, arranged in two sets. The central pipe, leading through the muffler, is of varying diameter and a part of the gas entering the muffler passes directly into the center chamber and

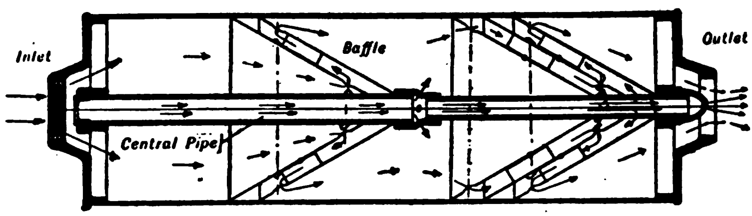
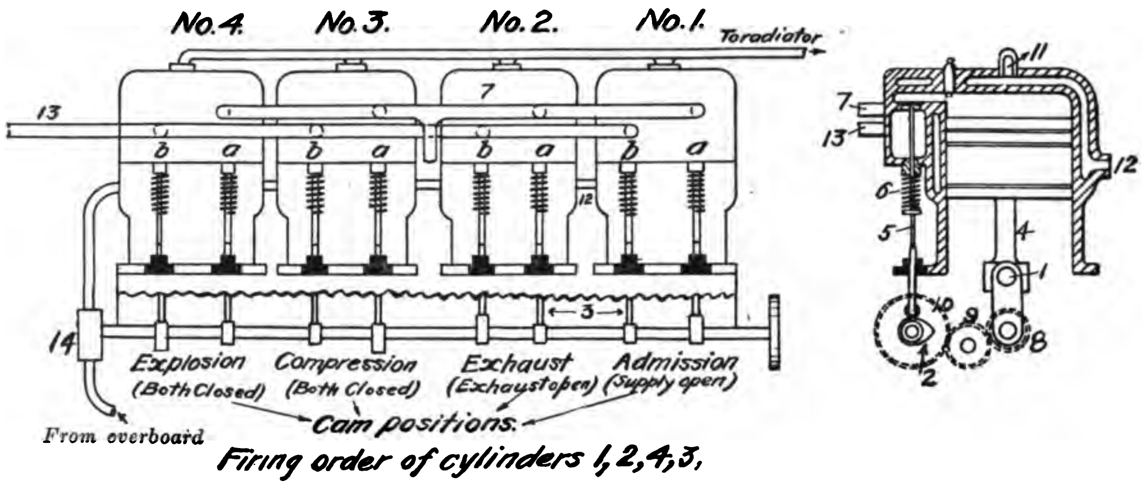


FIG. 17.—Ejector Muffler.

through the second set of cones before the gas which has entered the first chamber has passed through the first set. A portion of the gas is conducted straight through the center pipe to the nozzle at a high velocity which creates a partial vacuum in the



a. Admission Valves. b. Exhaust Valves.

1. Crankshaft.
2. Cam.
3. Pushrod.
4. Connecting rod.
5. Valve stem.
6. Valve spring.
7. Admission.
8. Gear on crankshaft.
9. Idle pinion.
10. Gear on camshaft.
11. Cooling water outlet.
12. Cooling water inlet.
13. Exhaust.
14. Circulating pump.

FIG. 18.—Camshaft or Countershaft, Illustrating Cam Positions.

third chamber. The rapid forward movement of the gas through the first and second chambers to the third causes a sudden expansion, removing the heat from the gas and reducing the pressure in the muffler to below that of the atmosphere. This allows the gas to escape without noise and without back pressure. This type was invented to increase the efficiency of automobile mufflers, but it is adapted to marine use with cooling water.

Camshaft for Multicylinder Engine.—In a multicylinder engine where there are numerous valves, etc., to be actuated by cams, a countershaft, called the cam shaft, is fitted. This is a small shaft, running the length of the engine, parallel to and geared to the engine main shaft. In addition to actuating all the valves this shaft sometimes actuates the timer, pumps, etc. It is geared to the main shaft of a four cycle engine in the ratio of one to two because each operation at any one valve must take place every second revolution. Fig. 18 shows the camshaft as operating in a marine or other high-speed engine. It is made of the best nickel steel. Engines designed with admission and exhaust valves on opposite sides of the cylinders require two camshafts.

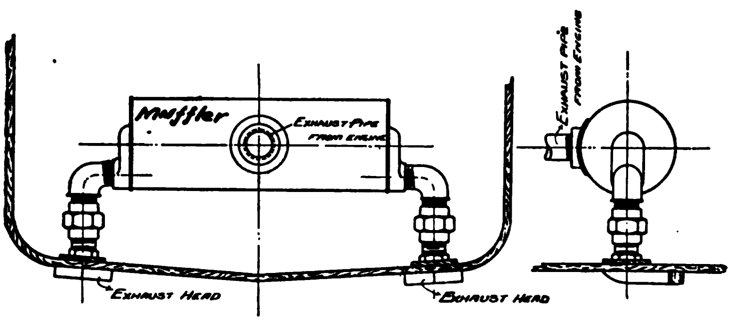


FIG. 19.—Underwater Exhaust.

Underwater Exhaust.—Fig. 19 illustrates a common form of exhaust below the water line. In this case there are two outlets from the muffler. This form is a little more expensive than that with one outlet, but it is used considerably with the ejector muffler.

CHAPTER IV.

TYPES, CYCLES, ETC.

Cycles.

"A cycle in engineering is any operation or sequence of operations that leaves the conditions the same at the end that they were in the beginning." An internal combustion engine cycle consists of: (1) suction or admission of the charge; (2) compression; (3) ignition, combustion and expansion; (4) exhaust. The number of strokes necessary to complete this cycle gives a means of cycle classification as follows: (1) two-stroke cycle; (2) four-stroke cycle. The common terms for these are two cycle and four cycle. The latter is sometimes called the Beau de Rocha cycle, or more commonly the Otto cycle. The two cycle is sometimes called the Clerk cycle.

Four-Stroke Cycle.

Figs. 20 to 23, inclusive, illustrate the four strokes forming a complete cycle in a four cycle engine. The piston is shown near the beginning of the stroke in each case. The admission valve communicates with the source of fuel supply.

Admission.—In Fig. 20 the piston is starting on the down stroke. During this stroke the admission valve is open and the vacuum formed by the down stroke of the piston is filled by the inrush of a fresh charge of combustible mixture. This is called the suction or aspiration stroke. The admission valve closes at the end of this stroke.

Compression, Fig. 21.—During this up stroke both valves are closed and the charge is compressed into a small space at the cylinder end called the "clearance space." The necessity for compression will be shown later.

Ignition, Fig. 22.—This third stroke is the power stroke and is variously known as the ignition, combustion, expansion, or explosion stroke. During this stroke both valves are closed. At the beginning of the stroke the charge is ignited and the subsequent expansion furnishes the motive impulse to the piston, driving it to the end of its stroke.

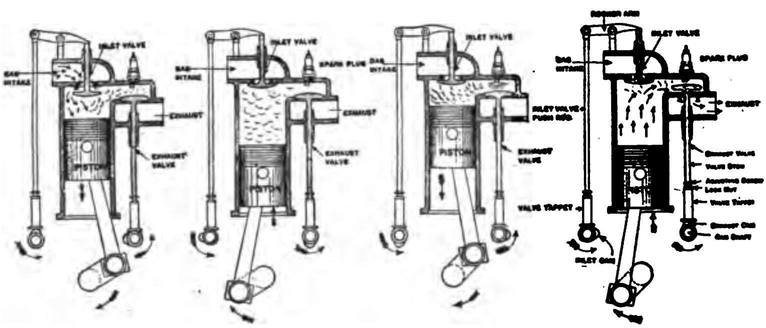


FIG. 20. FIG. 21. FIG. 22. FIG. 23.

Periods in the Cycle of a Four Cycle Engine.

Exhaust, Fig. 23.—The exhaust valve opens at or near the end of the expansion stroke and the up travel of the piston on this fourth stroke forces the gases of combustion out of the cylinder completing the cycle.

As the engine receives only one impulse every fourth stroke means must be employed to drive the engine throughout the remaining three. A fly-wheel, which accomplishes this by its inertia, is installed on the main shaft. In the case of multi-cylinder engines the fly-wheel by its inertia balances the impulses and gives a steady speed.

In a four cylinder engine the relative simultaneous positions of the pistons and valves would be as shown in Figs. 20 to 23 inclusive; the relative cylinder arrangements are shown in Fig. 18.

Two-Stroke Cycle.

The two cycle engine requires only two strokes or one revolution to complete the cycle. As seen from Fig. 24, the crank case is closed gas tight and a spring loaded admission valve opens to

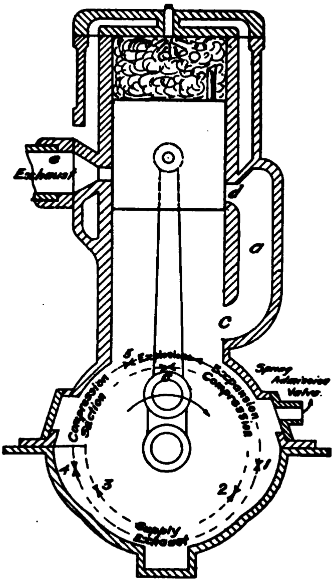


FIG. 24.

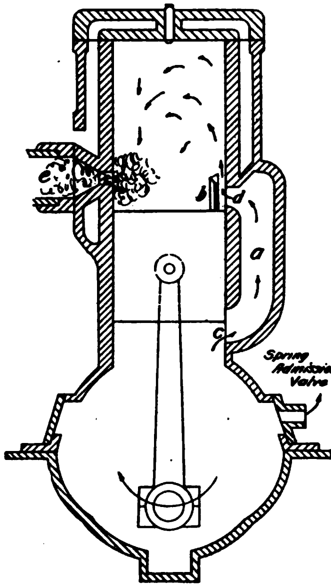


FIG. 25.

Periods in the Cycle of a Two-Cycle Engine,
Two-Port Engine.

the crank case. Instead of the admission and exhaust being regulated by valves, port openings in the cylinder sides are uncovered by the piston at proper points in the stroke and these openings communicate with the fuel supply and the exhaust passage. There are two general designs of the two cycle engine, (1) two port engine, (2) three port engine. The two cycle engine is sometimes called a valveless engine on account of the absence of valves. As the piston receives an impulse every other stroke, a fly-wheel is employed to drive the piston through the non-impulse stroke.

Two Port Engine.—The port *a*, Fig. 25, connects the crank case and cylinder around the piston, when at the bottom of its stroke. Deflecting plate *b* aids in scavenging the cylinder.

Two circles in the crank case, Fig. 24, illustrate the steps in the cycle. The inner circle indicates operations in the crank case and the outer circle indicates simultaneous periods in the cycle on top of the piston.

Working Stroke.—Starting from the position shown in Fig. 24, the charge is compressed in the top of the cylinder and has just been ignited. The crank case is full of a fresh charge that has just been drawn through the admission valve. The piston is driven down by the expansion. The port *d* being covered, the charge in the crank case is compressed on the down stroke. Expansion takes place in the cylinder to the point 1 and when this point is reached by the crank, the exhaust port is uncovered relieving the pressure. At the point 2, port *d* is opened allowing communication between the crank case and the cylinder. The compressed charge in the crank case rushes into the cylinder displacing the exhaust gases which escape through the exhaust port *e*, Fig. 25.

Compression Stroke.—On the return stroke when the point 3 is reached port *d* is covered by the piston and the up travel of the piston creates a vacuum in the crank case, which opens the admission valve and sucks a fresh charge into the crank case. At the point 4 the exhaust port is covered and from this point to point 5 the fresh charge on top of the piston is compressed. At point 5 ignition take place, completing the cycle. At 6 the spring loaded admission valve to the crank chamber closes.

Three Port Engine.—The Navy Type Engine, Figs. 26 and 27, is a good example of the three port engine. This engine does not require a spring loaded admission valve between the crank case and the carburetor. A third port (5) takes its place. The cycle is as follows:

Working Stroke.—Starting with the piston (1) at the top of its stroke, Fig. 26, the combustible charge of gas is compressed and ready for ignition. The charge in the combustion chamber (2) is ignited by the spark (3) and burned, and the resulting pressure forces the piston downward. At the beginning of this stroke the crank case (4) is full of combustible mixture that has been drawn in through the ports (5), and which is compressed to about five pounds by the piston on its down stroke. When near the bottom of the stroke, the top edge of the piston uncovers a series of ports (6) in the cylinder wall through which the burned gases escape to the exhaust pipe, the pressure in the cylinder dropping to near atmospheric. Shortly after the exhaust ports (6) have been uncovered, the piston, still moving downward uncovers the transfer ports (7) in the cylinder wall. These are situated diametrically opposite the exhaust ports. The transfer of the mixture from the crank case to the cylinder is made through ports (8) in the piston. These register with the ports (9) in the cylinder wall and admit the mixture into the by-pass (10), from whence it passes into the cylinder through ports (7). Ports (7) and (9) open and close simultaneously. To prevent the incoming charge from passing directly across the cylinder and out of the exhaust ports (6), transfer and exhaust ports being open at the same time, the top of the piston is provided with a baffle or deflector plate (11) which deflects the charge up to the top of the cylinder, thus aiding scavenging.

Compression Stroke.—On the up stroke, Fig. 27, the piston first closes the transfer ports (7) and shortly after the exhaust ports (6). The charge in the cylinder is compressed and at the top of the stroke is ready for firing. During this stroke a new charge is drawn into the crank case through ports (5) in the cylinder wall. Ports (5) are uncovered by the bottom edge of the piston (1) when at the top of its stroke.

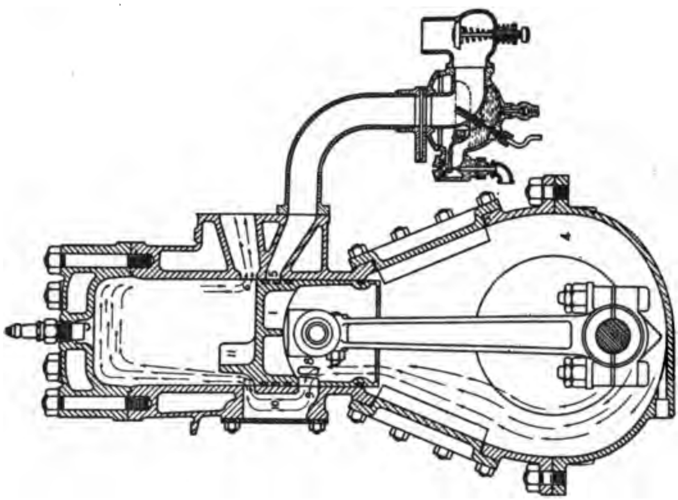


FIG. 27.

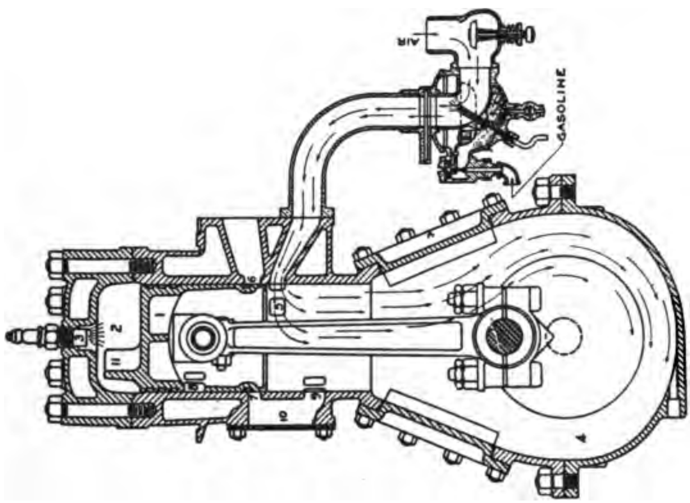


FIG. 26.

Three Port Engine.

Advantages and Disadvantages of the Two Cycles.

Two Cycle.—*Advantages.*—No valves, valve gear, cams and cam shaft; more uniform turning moment and lighter fly-wheel; smaller cylinder volume per unit of power; simplicity and compactness.

Disadvantages.—Loss of fresh fuel with exhaust reduces the economy; crank case must be kept gas tight to prevent loss of fuel and compression; fresh fuel entering the cylinder full of hot exhaust gases may cause premature explosion, and if this occurs before the admission port is closed, the crank case charge may explode, causing considerable damage to the engine. For large engines an auxiliary pump is employed to replace crank case compression.

Four Cycle.—*Advantages.*—Better explosion control; more economical; compression not dependent upon tightness of any part except valves and piston rings; no auxiliary pump required; gas tightness of crank case immaterial.

Disadvantages.—Cylinder volume and weight per unit of power greater; multiplicity of parts, especially valves, valve gear, cams, countershaft, etc., with increased probability of breakdown; loss of power if any valves are not gas tight.

The four cycle engine seems to lose in simplicity by comparison with the two cycle, but it is in far more general use. The two cycle engine predominates among small marine gasoline engines.

Although the two cycle engine receives twice as many impulses per revolution as the four cycle, it must not be concluded from this that, for the same cylinder dimensions, the two cycle has twice the power. In the four cycle type the impulse due to expansion is carried throughout nearly the entire stroke, whereas, in the two cycle type, the exhaust valve opens much earlier and the impulse only lasts about five-eighths of the stroke, as can be seen from Fig. 24.

Types.

The internal combustion engine is commonly called by a variety of names, none of which are technically correct for all types, for example, *gas engines, explosion engines, heat engines, etc.* Two

general subdivisions may be made, viz.: (1) single acting; (2) double acting.

A single acting engine is one which receives the motive impulse on only one side of the piston.

A double acting engine is one which receives the motive impulse alternately on both sides of the piston.

All small high-speed engines are single acting, and, with few exceptions, only large, heavy-duty motors are made double acting.

A very common and unscientific method of classifying internal combustion engines depends upon the fuel consumed, thus, gas engine, gasoline engine, oil engine, alcohol engine, etc. This is common commercial practice.

The only scientific classification is a thermodynamic one. Heat is imparted to the fuel and medium by the chemical reaction that follows ignition. The method of applying this heat to the working substance determines the class in which the engine belongs. The classification is as follows:

1. Engines receive heat, the charge being at constant volume.
2. Engines receive heat, the charge being at constant pressure.
3. Engines receive heat, the charge being at constant temperature.

Ignition with Charge at Constant Volume.

This class of engine is the one in most common use and is frequently erroneously called an *explosion* engine. The whole charge, which is drawn in on the aspiration stroke and compressed, is ignited, and, the charge occupying a small space, the rate of flame propagation is so rapid that the charge practically burns without change of volume before expansion takes place. In other words, combustion is complete before expansion starts. The subsequent rapid expansion, with its accompanying rise of pressure, furnishes the motive power. All engines using gas or *carbureted* fuel ignite at constant volume, and the Semi-Diesel engine approximates this type.

Ignition with Charge at Constant Pressure.

This principle was adopted by Brayton in his engine about 1870. He apparently got his idea from the action of the steam engine to which its cycle is analogous. Separate pumps supplied air and combustible to the cylinder at constant pressure and the mixture burned as it entered. The pressure was therefore constant during the expansion or combustion stroke until the admission valve closed. The increased volume at constant pressure drove the piston. This engine, which was at one time popular in this country, is no longer manufactured.

Ignition with Charge at Constant Temperature.

The card from an engine built on this principle would have a combustion line which, when analyzed, would prove to be isothermal. As late as 1904 the American Diesel Engine Company claimed this for their engine. This is rather surprising in view of the fact that isothermal combustion is theoretically the least efficient. It would be possible to construct an engine of the Diesel cycle whereby, air being previously compressed in the cylinder to a very high temperature, the fuel could be injected during the combustion stroke at such a rate as to maintain this temperature. This presupposes a very accurate and minute fuel supply regulation.

It can be shown mathematically that combustion at constant volume gives the most efficient cycle and that combustion at constant temperature gives the least efficient. Combustion at constant pressure gives a cycle which is between these two in efficiency.

Compression.

It was early recognized that compression, which immediately precedes ignition, is one of the greatest factors in internal combustion engine efficiency. With a given amount of fuel to be burned, if this fuel were not compressed, the cylinder volume

would necessarily be increased by the ratio of expansion and would be enormous were the engine non-compression. Thus it is apparent that compression is absolutely necessary.

By compressing the mixture into a small space the atoms of the fuel are more *intimately mixed,* thus *aiding combustion,* and they are brought more closely together thus *accelerating flame propagation.* Compression *heats the mixture,* thus *aiding ignition* and increasing the *initial temperature;* it also greatly increases the mixture's *power of expansion.*

By increasing compression the necessary clearance or *compression space is reduced;* this reduces the cylinder wall area of radiation and water jacket length and as a direct result the *loss of heat by radiation is diminished.* Reducing the clearance space is the equivalent of *increasing the stroke.* If compression is too low the fuel may not all burn, due to poor flame propagation, and some gases will not ignite at all unless compressed to a certain pressure.

The degree of compression that is necessary for efficiency depends upon the ignition point of the fuel, increasing with this temperature. There is a practical limit to the degree of compression that may be attained. This depends upon the ignition temperature of the fuel. As stated above, compression increases the temperature and, if this is carried too far, premature ignition will result. The following compression limits in pounds are given by Lucke:

Carbureted gasoline, high-speed engine	45-95
Carbureted gasoline, slow-speed, well-cooled engine	60-85
Kerosene, hot-bulb injection and ignition	30-75
Kerosene, vaporized	45-85
Natural gas	75-130
Producer gas	100-160
Blast-furnace gas	120-190

CHAPTER V.

CARBURETION, THE MIXTURE, ITS PREPARATION, CARBURETORS AND VAPORIZERS.

Definitions.—*Carburetion* is the process of saturating air or gas with a hydrocarbon.

The air or gas that is carbureted is called the ***medium.***

The *carburizer* is the agent (fuel) employed to saturate the air.

A *carburetor* is an apparatus used to charge air or gas with a volatilized hydrocarbon.

"*The mixture*" is the term commonly employed to designate the product of the carburetor when ready for combustion, viz.: the combination of fuel and air.

A "*rich*" mixture is one having an excess of fuel, and a "*lean*" mixture is one having an excess of air.

A "*charge*" is a cylinder full of mixture.

Carburetion.—Every fuel requires a certain amount of oxygen for complete oxidation or combustion. This can be supplied by the atmosphere if suitable means are at hand to mix the air and fuel. The various fuels contain different proportions of carbon, hydrogen and other combustibles, therefore, will require proportionate amounts of air to attain complete combustion. Excessive air will cool the mixture, greatly reduce the rate of flame propagation, and weaken the ignition if it does not actually prevent it. Its increased volume causes increased loss of heat in the exhaust gases. Too little air will result in incomplete combustion, which reduces the efficiency and causes carbon deposits in the cylinders.

The function of a carburetor or of a mixing valve is to admix the fuel and air to the correct richness, thus forming a combustible gas or vapor. The rapid advance in the development of the

modern internal combustion engine is due in large part to the perfection of satisfactory apparatus to carburet air. Successful working of such an engine is dependent upon the reliability, certainty, and satisfactory working of the carbureting device. Carburetion cannot be carried on at ordinary temperatures unless the fuel is very volatile. For the less volatile fuels heat is employed as an aid, and in this case carburetion consists of atomization and subsequent vaporization by heat.

The method adopted depends upon the fuel to be used, therefore carburetion will be treated under the following five heads: (1) gas; (2) gasoline; (3) kerosene; (4) oil; and (5) alcohol.

1. Gas.—Gas must be prepared for combustion by intimately mixing with air. This may be accomplished by pumping the gas and air together into the cylinder or into the space outside the admission valve. Another method is to introduce the gas and air into the cylinders through separate valves.

2. Gasoline.—This being one of the most frequently used fuels, its carburetion will be treated at length. It may be carried on by three distinct methods, the first two of which have practically fallen into disuse.

a. Surface Carburetion.—This, the earliest method used, consists of evaporating the liquid hydrocarbon by passing a current of air over the surface of the liquid. The air thus becomes saturated by evaporation of the liquid from its free surface. This method is practically obsolete for the following reason: Evaporation from the free surface of gasoline will tend to volatilize the lighter hydrocarbons, leaving a liquid of rapidly increasing density, which finally loses its volatility at ordinary temperatures.

b. Mechanical Ebullition.—By introducing a current of air below the surface of gasoline and allowing it to bubble to the surface a certain amount of the liquid is entrained as mist in the air. This method was abandoned also for practically the same reason as the former.

c. Spray Carburetion.—This is the only practical method now employed to convert gasoline into a combustible vapor. Each

suction stroke of the piston creates a vacuum in the cylinder, which vacuum sucks the air into the cylinder through the mixing chamber of the carburetor. This air is at a pressure below that of the atmosphere. The mixing chamber communicates with the gasoline chamber of the carburetor by a fine nozzle or needle valve. As the air passes over this nozzle a spray of gasoline is sucked through it into the passing air which it saturates. This is made more clear by a study of the carburetor itself.

Carburetor Requirements.—A good carburetor or mixing valve must fulfill the following requirements: (1) it must be adjustable so that the correct proportion of fuel and air is obtained; (2) this proportion must be maintained at varying speeds; (3) if possible, the location of the spraying nozzle should be near the middle of the air passage; and (4) the apparatus must be simple and compact.

The distinction between a mixing valve and a carburetor will be seen from a description of each. In both cases fuel is drawn through a nozzle into the air which is being sucked into the cylinder. A mixing valve has its nozzle below the source of fuel supply and this nozzle is opened and closed by a valve which is lifted at each aspiration stroke of the cylinder. A carburetor has its nozzle just above the gasoline level in the gasoline chamber of the carburetor and the fuel is sucked through the nozzle by the air on each aspiration stroke. In either case the flow of gasoline vapor stops when the engine is stopped.

The Schebler Carburetor is one of the most popular and efficient of the high-speed carburetors. Model D is shown in Fig 28. The opening marked "gasoline" is connected to the gasoline tank by piping. Gasoline enters at *G* and passes through float valve *H* to the float chamber *B*. The opening *R* connects to the engine intake pipe, and *A* opens to the atmosphere. When running, the engine suction at *R* draws air in at *A*, and as this air rushes past the spraying nozzle *D*, gasoline is drawn from *B* through *D* and carburets the air which passes through *R* to the engine. The amount of opening at *D* is regulated by the needle valve *E*.

The gasoline in B is maintained at a constant level by the float F as follows: As the gasoline in B is drawn through D the level in the chamber B falls and float F falls with the gasoline level. This float, through a toggle hinged at J, opens the float valve H admitting gasoline to B. As the gasoline level in B rises it lifts the float F until the valve H is closed. This operation is continuous.

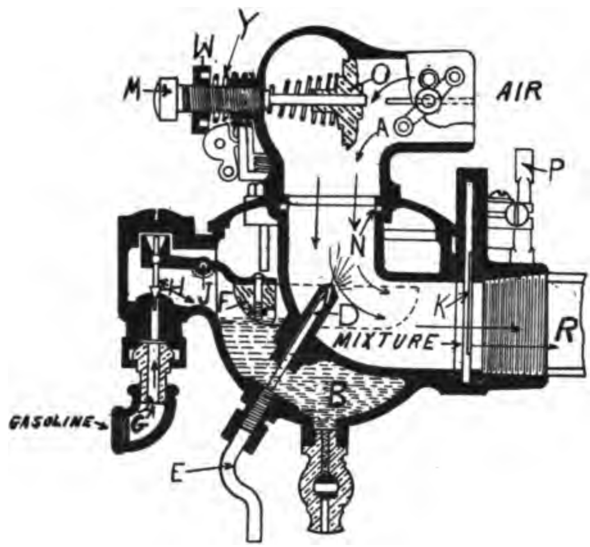


Fig. 28.—Schebler Carburetor, Model D.

The amount of entering air is regulated by the air valve O. When the motor is running at its maximum speed, air is drawn through an aperture of fixed dimensions. As the speed is increased, and consequently the flow of gasoline becomes greater more air is required and this additional air is supplied by the compensating air valve O, which opens an amount proportionate to the speed. The amount of air valve lift is regulated by the air valve adjusting screw M, which in turn is locked by the spring Y and lock nut W.

The quantity of mixture admitted to the engine is regulated by the throttle disc *K*, which is operated by the lever *P*. This regulates the engine speed. The butterfly disc, shown dotted in the air intake, is used when starting. Closing this cuts off most of the air and enriches the mixture. It is kept open when running.

The joint between the carburetor and gasoline piping is a ground joint with a reversible union so that this joint can be broken without disturbing the carburetor or piping. Joint *N* is made air tight by a cork gasket.

The Lunkenheimer Mixing Valve, Fig. 29.—Air entrance is effected at 1. Gasoline enters at 3 through the needle valve passage 4. The amount of entering fuel is regulated by the needle valve which is operated by the graduated wheel 5. The mixture leaves for the engine at 2, after passing over the mixing baffle 6. On each aspiration stroke valve 7 lifts, uncovering the needle valve passage. Air is sucked to the upper chamber, drawing gasoline from the needle valve. The valve is seated by its spring at the end of the aspiration stroke, and its lift is regulated by the stop 8. Passage 2 contains a throttle.

There are innumerable carburetors and mixing valves on the market and the above are chosen as typical designs.

General.—It is advantageous, especially in cold weather, to have the source of air supply warmer than the atmosphere. Many methods are employed, such as having the air suction drawn from the proximity of the hot exhaust pipe, leading the hot exhaust gases around the admission pipe, or jacketing the carburetor with the exhaust gases or heated exhaust circulating water. 80° F. to 85° F. is the best temperature for admission. The temperature and hygrometric condition of the air supply regulate the relative quantities of air and fuel required in the mixture. It will be necessary to regulate the mixture to meet the varying atmospheric conditions.

3. Kerosene.—There are two methods of treating this fuel: (a) carburetion, similar to gasoline; and (b) injecting into the cylinder or vaporizer near the air valve, as in the case of the heavier oils.

a. Carburetion of kerosene, as stated before, requires the application of heat to aid vaporization at ordinary temperatures. Therefore, the process consists of two parts, first atomizing the fuel in a similar manner to gasoline carburetion and then vapor-

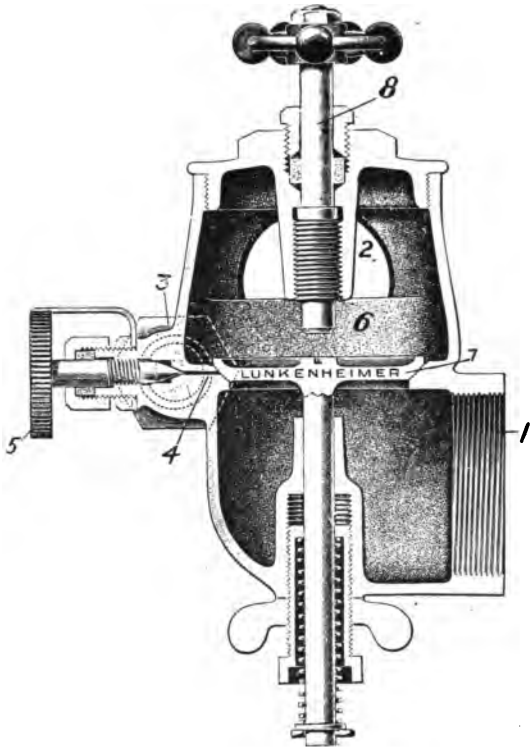


FIG. 29.—Lunkenheimer Mixing Valve.

izing this spray by heating. This heat is applied either by jacketing the carburetor or admission pipe, or by heating the air before passing the same through the carburetor. Any well designed gasoline carburetor with a hot air intake, if jacketed, will carburet kerosene, but not efficiently. Some kerosene carburetors start on gasoline and shift to kerosene after the engine is started

and well warmed up. Such a carburetor is similar to the alcohol carburetor shown in Fig. 31.

b. Kerosene may be injected into the cylinder direct and the necessary air supplied by a separate valve. Means are employed to regulate the amount of fuel that is drawn into the cylinder each suction stroke. The passage of fuel through its valve atomizes it, and upon contact with the hot cylinder or vaporizer walls it is vaporized.

Crossley Vaporizer.—In Fig. 30 the vaporizer is shown attached to the cylinder head. It is ribbed to facilitate heating for

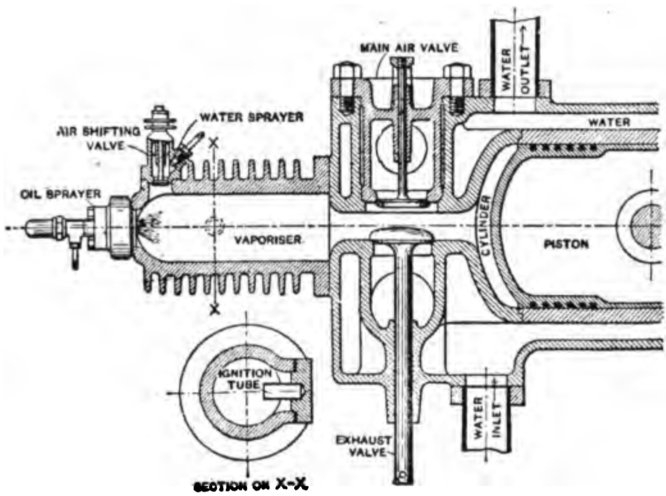


FIG. 30.—Section of New Crossley Vaporizer and Valve Chamber.

starting and to regulate the temperature when the engine is running. The oil sprayer supplies kerosene to the vaporizer, where it vaporizes on contact with the hot vaporizer walls. The heat of compression keeps these walls hot when the engine is running, and near the highest compression point the ignition tube (shown in section) becomes sufficiently hot to fire the mixture. The air shifting valve permits water spray to enter the cylinder. This regulates the cylinder temperature and reduces carbon deposits.

4. Oil.—Heavy oils, those heavier than kerosene, are generally sprayed directly into the cylinder. Air is forced through a separate valve into the cylinder either with or ahead of the fuel. There are two distinct methods of vaporizing and igniting heavy oil, and this leads to two types of engines, the Semi-Diesel and the Diesel. They are different, both mechanically and thermodynamically.

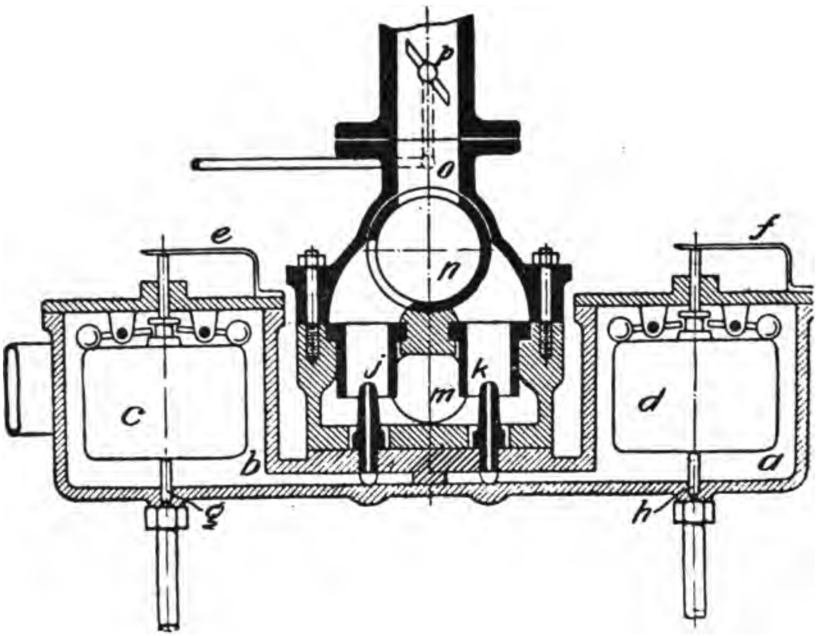
The Semi-Diesel Engine compresses the air to about 85 to 215 pounds per square inch. The temperature is *lower* than the ignition temperature of the fuel. At the beginning of the *working stroke all* the fuel is injected against a hot bulb shown in Fig. 30, which vaporizes and ignites it, practically instantaneously. The pressure rises to about 260 to 350 pounds per square inch. The engine approximates the constant volume type.

The Diesel Engine compresses the air to about 500 pounds per square inch. This gives a temperature *higher* than the ignition temperature of the fuel. During the first part (about 1/10) of the *working stroke,* fuel is injected into the cylinder. It is ignited by the heat of the compressed air and combustion takes place throughout the injection period, fuel being supplied at such a rate that combustion takes place at approximately constant volume.

Both types are equipped to supply scavenging air at about five pounds pressure. One of the most difficult features of design connected with "heavy oil" engines is to reduce the deposits of carbon that tend to form. When a heavy oil is volatilized there is a strong tendency toward chemical change. Its heavy hydrocarbon constituents tend to decompose into lighter ones. This reaction, called "cracking," which is absent when the lighter fuels are carbureted, leaves a carbon residue. Many installations inject small quantities of steam or water into the cylinder during the cycle to reduce the temperature at the beginning of combustion. The real beneficial result to be expected is that carbonization may be reduced, the moisture maintaining the carbon in a spongy state so that it may be blown out at the exhaust instead of being deposited. This is not general marine practice, but is

worthy of investigation. Practically all large marine heavy oil engines today are Diesel engines. This engine is described in Chapter XII.

5. Alcohol.—Correct carburetion of alcohol is more difficult than would be suspected by an inexperienced operator. Excess of air creates increased loss of heat through the exhaust gases and retards ignition, but a deficiency of air causes much more serious trouble. The resulting incomplete combustion causes the formation of corrosive and fouling products which corrode and clog the cylinders, valves, etc. Like kerosene, alcohol requires auxiliary heat for vaporization, although some few carburetors have been built without provision for heating the atomized product. The heat may be applied by any of the ways enumerated under kerosene. The future form of carburetor for alcohol seems prob-



Gasoline. Alcohol.

Fig. 31.—Alcohol Carburetor.

lematical, but a likely type is shown in Fig. 31. This carburetor, known as the double float type, is constructed to use either gasoline or alcohol, thus permitting the start to be made on gasoline (which will volatilize cold) and subsequent running to be done on alcohol. Suppose that compartment *b* is used for gasoline and *a* for alcohol. *c* and *d* are floats in these chambers that regulate the level of liquid in the chambers by opening and closing the needle valves *g* and *h*. *e* and *f* are springs that can be used to keep either needle valve (*g* or *h*) closed when the other is in use. *j* and *k* are nozzles communicating with the fuel chambers *b* and *a*. *m* is the air inlet and *n* is a valve which can be so rotated as to connect the air inlet *m* with the admission pipe *o* by way of either *j* or *k*. *o* is the admission pipe to the engine and *p* is a throttle. The carburetor is shown with both needle valves closed.

The operation is as follows: Using gasoline to start, push aside the spring *e* allowing the float *c* to operate and admit gasoline to *b*. With the valve *n* in the position shown, the apparatus becomes a simple float valve gasoline carburetor. Air is drawn in through *m* over *j*, sucking up gasoline vapor, through *n* and out at *o*. When the engine is warm and it is desired to shift to alcohol, the spring *e* is pushed to the closed position and *f* is pushed aside, allowing the float *d* to operate. The valve *n* is turned so as to connect *m* and *o* by way of *k*. We now have a simple float valve alcohol carburetor, the air being drawn into *m* over *k*, sucking up alcohol vapor, and going out by way of *n* and *o*. This type of vaporizer is supplied with *preheated* air.

CHAPTER VI.

IGNITION.

Next to carburetion, the most important feature in internal combustion engine operation is proper ignition. The abandonment of naked flame ignition because of its uncertainty leaves three general methods of igniting the compressed mixture: (1) the electric spark; (2) by contact of the mixture with a heated tube; (3) by compressing the charge until its temperature reaches the point of ignition. The first method, that of the electric spark, is the one in most common use, the reasons being that it has reached a nearly perfect state of development and it can be more easily "timed."

Timing the spark means regulating the point in the stroke at which ignition takes place. For high-speed engines electrical ignition is the only one flexible enough for accurate regulation. It is obvious that with an engine running at 600 revolutions per minute, the stroke being but 1/20 second, it would be extremely difficult mechanically to vary to a nicety the point in the stroke at which ignition will take place.

Electric Spark.—By shooting a hot electric spark through a compressed charge ignition will take place. Electrical ignition may be subdivided into two classes: (1) jump spark system; (2) make and break system.

1. Jump Spark.—This system requires among other things a spark plug, which is shown in the circuit in Fig. 32. A current of high potential is made to jump across a gap between two terminals of the spark plug. This plug, which is screwed into the cylinder head, has its gap surrounded by the compressed mixture at the moment of ignition. Closing the circuit causes the spark to leap and this ignites the charge.

A Single Cylinder Ignition Circuit is shown in Fig. 32. The spark plug steel casing *a* screws into cylinder head *b*. This grounds terminal *g* at the engine. The other terminal *h* is insulated from the rest of the plug by the porcelain collars *c* and *d*.

f is a gas tight washer of asbestos. These collars and washers are made in a variety of shapes and of different materials, but the principle is the same in all cases.

The system consists of two circuits, a primary and a secondary. Following the primary circuit, shown by the heavy line, it goes from the ground *J* through the battery *K* to the vibrator *L*, through the primary windings of the induction or Ruhmkorff coil *M* to the terminal *N* of the timer. The timer shaft *O* revolves, and this shaft being grounded, the circuit is completed by the cam

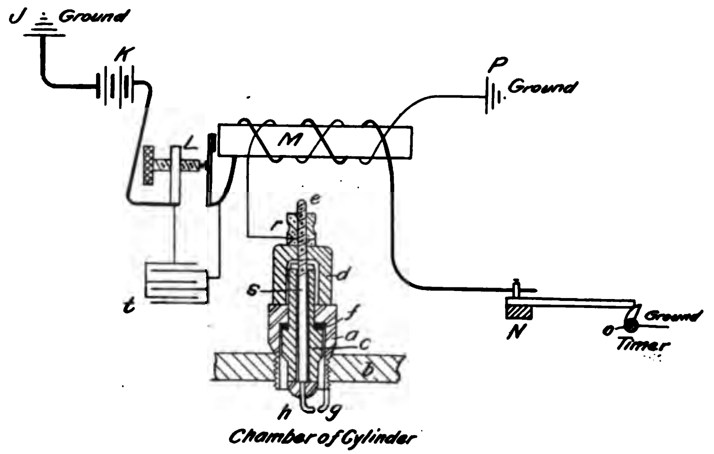


FIG. 32.—Single Cylinder Jump Spark Ignition, Showing Details of Spark Plug.

on the shaft. The secondary circuit leads from the ground *P* through the secondary windings of the coil *M* to the terminal *r* of the spark plug, then down the spindle *s* to the point *h*. The point *g* being grounded, the circuit is completed by the gap between the two points of the plug. When the primary circuit is completed by the timer, sending current through the primary windings of the coil, a high tension current is induced in the secondary windings and this current is strong enough to overcome the resistance of the gap, which it leaps. *t* is a condenser connected across the terminals of the vibrator. Its function is to damp the break spark at *L*.

The Induction Coil M consists of an iron core surrounded by a few layers of heavy wire, *primary windings*. On these, in turn, are many turns of fine wire, *secondary windings*, wound in the opposite direction. All windings are insulated from each other and from the core. The function of the *coil and vibrator* is to convert the direct battery current of low potential to current of high potential, partaking of the nature of a rectified alternating current, for use at the plug. The high tension alternating

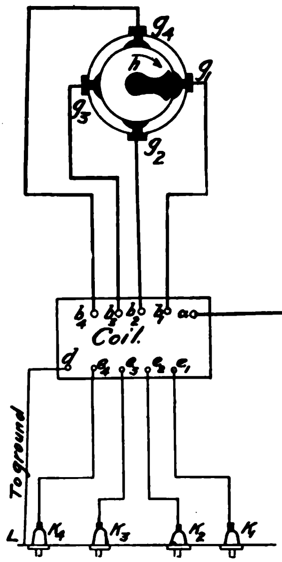


FIG. 33.—Wiring for Four Cylinder, Jump Spark Ignition.

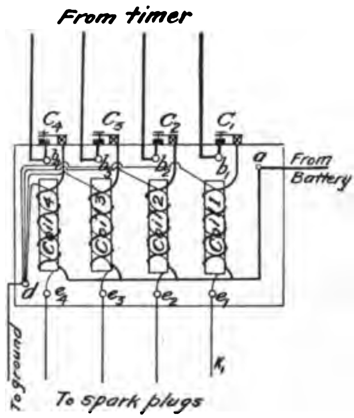


FIG. 34.—Wiring of Coils.

current gives a hot vibrating spark. The induction coil must not be confused with the "spark coil" described under "make and break" circuits.

Multicylinder ignition, Fig. 33, illustrates four-cylinder engine wiring. Fig. 34 shows the wiring of the coil. The timer shaft h revolves, making contact with the terminals, g_1, g_2, g_3, g_4 in succession. h is grounded to the engine. a, b_1, b_2, b_3, b_4, e_1, e_2, e_3,

e_4 are plugs on the outside of the coil box and are connected as shown in Fig. 34. The plug *a* connects to the battery, *d* to the ground, e_1, e_2, etc., to the spark plugs, and b_1, b_2, etc., to the terminals g_1, g_2, etc., of the timer. k_1, k_2, etc., are the spark plugs. c_1, c_2, etc., are the buzzers. The shaft *h* being in the position shown, the primary circuit goes from ground *h*, through g_1 to b_1, through vibrator c_1 and primary windings of coil 1 to plug *a*, thence to battery and ground. The secondary circuit 1 leads from ground *L* to plug *d*, through secondary windings of coil 1, where a high tension current is induced, to plug e_1, thence to spark plug

Fig. 35.—Splitdorf Timer, Roller Type.

k_1. This circuit is similar to the one cylinder circuit described above. When shaft *h* is revolved to make contact with g_2, the current flows through coil 2 to spark plug k_2, etc., and in this manner the cylinders are ignited in rotation.

The Timer.—Means must be employed with a multicylinder engine to ignite each cylinder in turn at precisely the proper instant. This is accomplished by the timer. It is interposed in the primary circuit with a terminal for each primary wire from the coil, Fig. 33.

Fig. 35 illustrates the Splitdorf timer. The shaft *A*, which is revolved by gearing from the cam shaft, is grounded, and carries the roller contact *F*. The terminals, *B*, *C*, *D* and *E*, are insulated from the rest of the timer. The primaries for each cylinder lead from the coil to these terminals. As the roller *F* makes contact with the plates *G* of each terminal it completes the primary circuit of the cylinder corresponding, firing each cylinder in turn. The spark can be advanced or retarded by rotating the collar carrying the terminals by means of a lever attached to *H*.

Magnetos and Generators.—A magneto differs from a dynamo in that its magnetic field is furnished by permanent magnets. A generator is in effect a small dynamo, its magnetic field being created by electromagnets. Thus the magneto is the lighter and simpler machine and is preferable for some uses. Where the machine is intended for ignition only the magneto is generally used. If considerable current is required over that necessary for ignition (such as lighting in an automobile system), the generator is used because the continual drain would cause magneto magnets to lose their strength. Magnetos are classified as high tension and low tension.

High Tension Magnetos are used for jump spark ignition. They deliver a high potential alternating current. To deliver this high potential the armature is made of many fine windings or the magneto has a self-contained transformer coil.

An ignition circuit using the high tension magneto consists only of the magneto and wiring to each spark plug. By means of a distributor (similar to a timer) built into the magneto, the high-potential current is supplied to each plug of the engine in turn at the correct point of the cycle for ignition.

Low Tension Magnetos are used for make and break ignition. They deliver a low potential direct current which seldom exceeds 100 volts. As this is insufficient to leap the spark gap, a *spark coil* is placed in the circuit to increase its capacity. Sometimes this spark coil is built into the magneto to form a self-contained ignition system.

The Spark Coil, as used in the make and break system, consists simply of an iron core on which is wound a number of layers of insulated No. 14 copper wire. This coil is placed in series with the source of current supply and the make and break apparatus. The effect, when the circuit is broken, is to cause an instantaneous and hot spark. On account of its action the spark coil is sometimes referred to as a "booster."

Distributors perform a similar function in the secondary circuit to that performed by the timer in the primary circuit. Fig. 36 illustrates a four cylinder ignition system with Bosch High

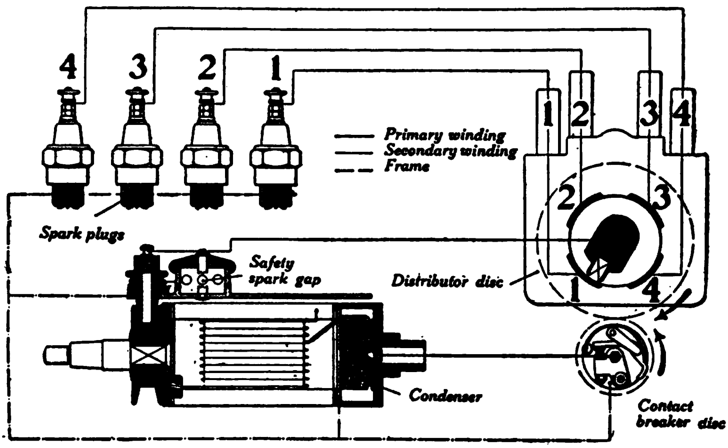


FIG. 36.—Four-Cylinder Ignition, Bosch High-Tension Magneto.

Tension Magneto, having a contact disc or timer in the primary circuit and a distributor in the secondary. The armature carries two windings, one indicated by the heavier lines at the bottom, called the primary, the other, composed of finer wire, called the secondary. One end of the primary winding is grounded, the other is connected to the fixed terminal of the contact breaker or timer. This end is also joined to one end of the secondary winding and the free end of the secondary winding is connected to the collector ring carried by the ebonite spool. When the contact points separate, a current is induced in the primary and

secondary windings and is delivered to the central terminal of the distributor disc by the carbon brush that bears against the collector ring. The various segments of the distributor are connected to the spark plugs in the cylinders, and every time the contact points separate a spark will be produced at one of the plugs because the revolving distributor brush will be in contact with one of the distributor segments.

Fig. 37 illustrates a combined timer and distributor. The revolving member, which attaches to the drive shaft (grounded), carries as many roller contacts as there are cylinders to be fired,

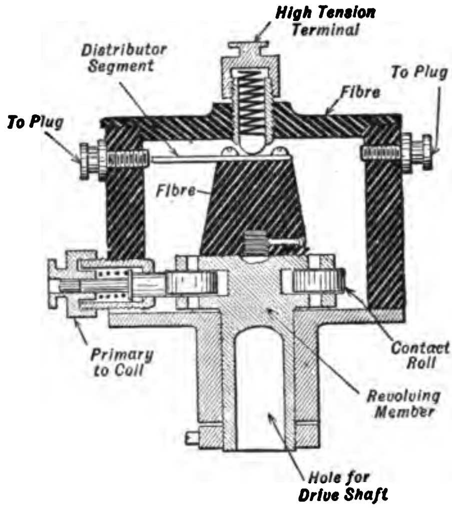


FIG. 37.—Combined Timer and Distributor.

these being spaced properly to insure correct timing. One primary terminal to the coil is screwed into the fiber casing, making contact with the rolls and completing the primary circuit as the shaft revolves. Secured to the revolving member is a fiber crown which carries a distributor segment. This is always in contact with a high tension terminal (secondary terminal from the coil) in the distributor head. As the shaft revolves the distributor segment makes contact with terminals that connect to the plugs. This completes the secondary circuit.

2. Make-and-Break System.—This system, which is a mechanico-electrical one requiring cam or other gearing to make and break a contact inside the cylinder, is applicable to slow speed engines, and for this special duty has some advantages over the jump spark. A moving contact in the electrical circuit is mechanically made and broken inside the cylinder. At the *break* a spark will leap between the contacts igniting the mixture. This system admits of two methods: (1) the wipe spark; (2) the hammer break. By the first method the contacts are made to brush together and by the second the contacts are brought together sharply and separated. The wiring for both methods, shown in Fig. 38, is similar. A small coil is employed to step up the current, but no vibrator is used, as this would cause a spark to occur

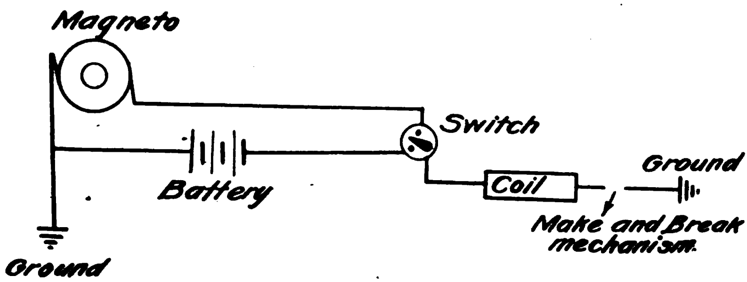


FIG. 38.—Circuit for Make and Break Ignition.

at make as well as break, thus probably igniting the charge prematurely. Either battery or magneto current may be used in the circuit shown in Fig. 38.

Wipe Spark mechanism is shown in Fig. 39. The rod *b* oscillates the collar *a* by means of a cam *c* on the countershaft. The collar *a* carries the contact point *d*, grounded to the engine. As the collar *a* oscillates the point *d* wipes past the spring point *e* completing the circuit. The spring *g* quickly returns the collar to its original position when the cam releases the rod *b*, and the circuit thus being broken a spark will occur between the points *d* and *e*. The source of current is connected to *e* by the terminal *f*. Terminal *f* and point *e* are insulated from the rest of the mechanism.

The advantage of the wipe spark over the hammer break lies in the fact that the sliding contact prevents carbon deposits on the points.

Hammer Break.—The principle of the hammer break is shown in Fig. 40. The spindle *a*, carrying the contact *b*, is actuated by cam and rod through the lever *c*. *d* is a spring to keep *b* against

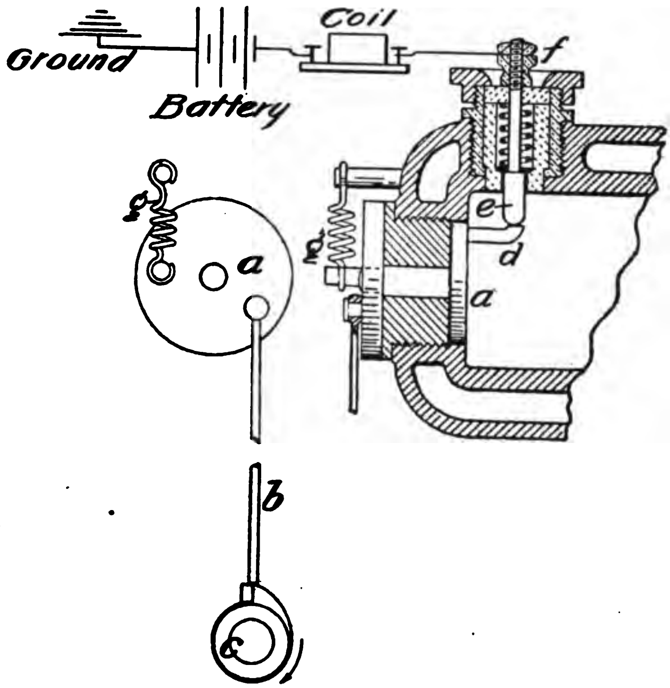


FIG. 39.—Wipe Spark Igniter.

the collar. *f* is the cylinder head. Contacts *b* and *e* are inside the cylinder and *b* is grounded to the cylinder. Contact *e* is insulated from the cylinder and its terminal *g* is connected to the source of current. When the contacts *e* and *b* are separated mechanically, a spark occurs. The cam actuating this gear is generally situated on the camshaft of the engine.

Comparison of the Different Electrical Systems.—The make-and-break system is the simpler electrically and less insulation and short circuit troubles occur because a low tension current is used throughout. It is mechanically more complex, hence it is more suitable for low-speed engines and hard to adapt to high-speed engines.

Although electrically more complex than the make-and-break system, the jump spark system has no moving parts inside the cylinder, and its flexibility as regards spark adjustment makes it the universal system for high-speed engines.

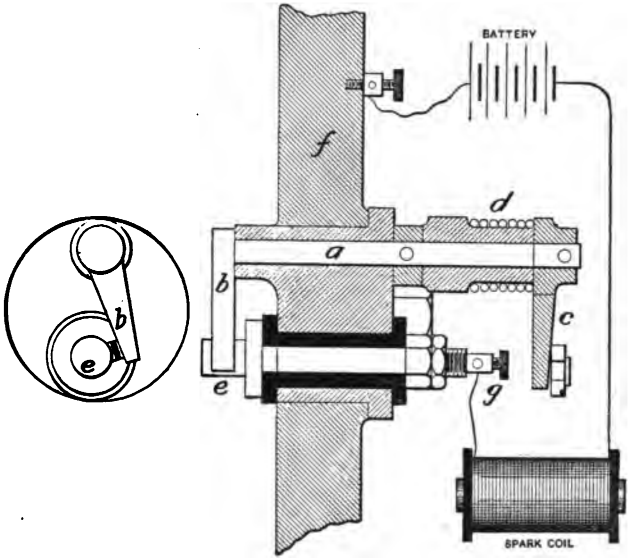


Fig. 40.—Hammer Break.

General.—All contact points and spark plug points are made of a platinum alloy or other heat resisting conductor. The points must be kept clean and free from carbon, as this formation tends to form short circuits across the gap, thus damping the spark. All connections should be so arranged that they cannot jar loose, and the insulation must be protected from heat, oil, and especially water.

Dual Ignition.—By a " dual ignition" system is meant one in which the current is supplied from either a battery or magneto, or from both, at will. Some systems have a separate set of spark plugs for each source of current supply, and in this case the system is in effect two separate systems. The dual ignition system proper, in which current may be obtained through one set of plugs from either battery or magneto, is shown in Fig. 41.

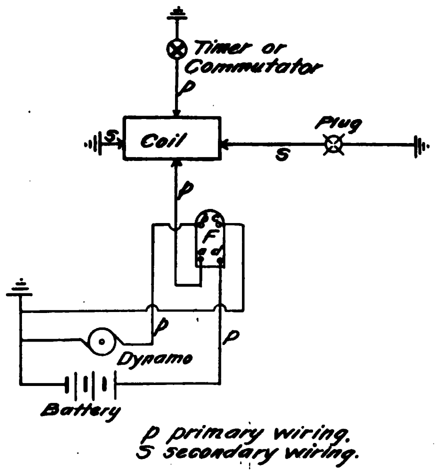


FIG. 41.—Dual Ignition Circuit.

F is a four way switch which operates as follows: Connecting *a* and *b*, the current goes from the dynamo to the primary of the coil direct where it is converted to high tension current. Connecting *a* and *d* the current goes from the battery direct to the primary of the coil. Connecting *c* and *d* the voltage of the battery can be read by a volt-ammeter in the circuit. The secondary circuit *s* is similar to that shown in Figs. 33 and 34.

This should not be confused with double ignition, in which there are two separate circuits and sets of spark plugs, one for the battery and one for the magneto.

Two-Point Ignition.—There is a tendency in modern practice to have two spark plugs for each cylinder, so as to ignite the

charge at two points nearly simultaneously. This is theoretically excellent, as it will accelerate flame propagation, but there are several difficulties that are hard to overcome. First, the two sparks must occur at correctly timed instants, otherwise the object of the system would be defeated. Second, if the two spark plugs are situated close together little benefit is derived. The first difficulty has been overcome, and where design permits the installation of two spark plugs widely separated excellent results follow. A large proportion of aerial motors are equipped with two-point ignition.

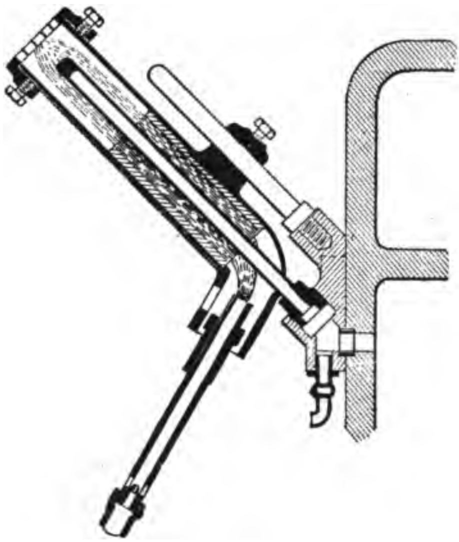


FIG. 42.—Hot Tube Igniter.

Hot Tube Ignition.—Although rapidly being superseded by electrical systems, the hot tube is still being furnished by some manufacturers. A typical hot tube igniter is shown in Fig. 42. One end of a small tube communicates with the cylinder, the other end is closed. A Bunsen burner, located in a surrounding chimney, keeps part of the tube at a red heat. The chimney is partially lined with asbestos or other non-conductor, which reduces loss of heat by radiation.

On the exhaust stroke the tube is filled with exhaust gases. On the suction stroke part of these gases remain in the tube. On the compression stroke the exhaust gases are compressed into the closed end of the tube and some fresh mixture is compressed into the cylinder end of the tube. When the fresh charge reaches the hot part of the tube it ignites, and near the dead center, when the velocity of flame propagation exceeds the velocity of the entering mixture, explosion takes place. The point of ignition may be varied by shifting the chimney along the tube by use of the set screw shown. Accurate timing for slow-speed engines is obtained by inserting a valve at the cylinder end of the tube. By opening this valve at the correct point in the stroke the fresh mixture comes in contact with the hot tube. The valve is actuated by cam gear from a camshaft.

Ignition by Compression.—When a gas is compressed its temperature rises and it is possible to compress the mixture to the point of ignition. There are two distinct methods of applying this principle.

a. Diesel Method.—Air is compressed in the cylinder until its temperature is far above the ignition point of the fuel and the fuel is injected into this heated air during the working stroke.

b. Semi-Diesel Method, sometimes called the hot bulb method, is described under carburetion of heavy oils. Referring to Fig. 30, a bulb (vaporizer) on the cylinder head is maintained at ignition temperature by the heat of compression. To start the bulb must be heated by an outside flame. When gas is the fuel, the oil sprayer is omitted. Compression is so regulated that on the compression stroke the velocity of flame propagation will exceed the velocity of gases entering the neck of the bulb at the proper point in the stroke for ignition. Timing the point of ignition is accomplished by regulating the compression pressure.

CHAPTER VII.

COOLING AND LUBRICATION.

Cooling the Gases.—One of the measures of efficiency for an internal combustion engine is the effective utilization of the available heat energy. This in turn depends upon the initial and final temperatures of the gases that develop the pressure, if these gases be cooled as far as possible by transforming their heat into work. Experiments have been made along the line of injecting water into the cylinder both before and after ignition of the charge, on the theory that the heat absorbed from the ignited mixture would vaporize the water and reappear as work on the piston in the form of pressure due to adiabatic expansion of the water vapor. Although this reduces the loss of heat in the exhaust, it is open to the objection that it reduces the net effective pressure. The practice of injecting water into engine cylinders has been revived in the past few years, it having been demonstrated that carbon deposits are thereby reduced.

Cooling the Cylinder.—At the moment of ignition the temperature of the gases rises very high, sometimes to 3,000° F. Due to the high heat developed by the combustion of the mixture, it becomes necessary to cool the metal of the cylinder walls, pistons, valves, etc. Were this temperature not reduced the result would be leaky valves, deformations, defective alignment, seizing of piston, and oxidation of metal. Also it would be impossible to lubricate the cylinder walls because the lubricant will burn as fast as it is applied to the walls.

Ordinarily the most efficient temperature for the entering mixture seems to be between 80° F. and 85° F. Cooling water is generally carried near the boiling point, say about 180° F. In a well designed engine the cylinder wall temperature will be about 75° higher than the cooling water temperature. This is sufficiently low to prevent deformation of the cylinders. There are two methods of cooling the cylinder: (1) water cooling; (2) air cooling.

Water Cooling.—The cylinder is jacketed and water is circulated through the jacket. Where unlimited water is available the exhaust is led to a drain. If the water supply is limited a tank is employed. Fig. 43 illustrates the use of a tank and the thermo-syphon system. The circulating water enters at the bot-

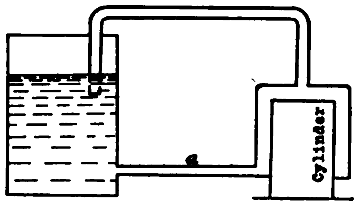


FIG. 43.—Thermo Syphon System.

tom of the jacket and, as it becomes heated, rises, flowing out at the top to the tank. A continuous circulation is thus established. When this system does not furnish a circulation that is rapid enough, a pump is placed in the supply pipe *a*. For slow speed engines this pump may be of the plunger type, if the water is free from foreign particles such as dirt and marine growth, or of

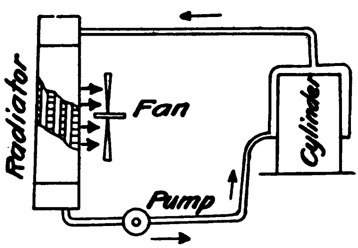


FIG. 44.—Water Cooling, Radiator and Pump.

the centrifugal type if the water is not clear, as in marine practice. The pump is designed for the probable working speed because one that would supply sufficient water at a designed high working speed would be deficient at low speed, and one that was designed for a low speed might cool the cylinder to too low a point for efficiency at high speed.

Fig. 44 shows the system used for cooling automobile and aeroplane engines, where a limited amount of water can be carried. The radiator shown consists of a top and bottom header connected by vertical tubes. These tubes are covered with thin fins to increase their radiating surface. The honeycomb type, commonly seen on automobiles, has nearly superseded this type. The water enters the cylinder jacket at the bottom, flows out at the

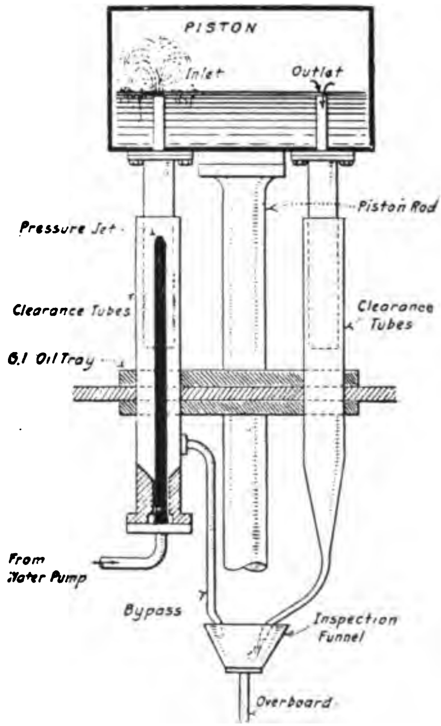


FIG. 45.—Werkspoor Piston Cooling System.

top, heated, and returns to the radiator where it is cooled by passing through the tubes. The circulation is aided by a pump, and a fan circulates the air through the radiator between the tubes. By reusing the circulating water it is "broken," that is, the salts are precipitated, hence there will result less sediment in the jackets.

Cooling valves, pistons, etc.—In all large engines the heat from the piston will not radiate to the cylinder walls rapidly enough to maintain a safe piston temperature. This necessitates independent provision to water cool the piston. Water is introduced to hollows cast in the piston, either by flexible connections or by two hollow tubes that slide through a stuffing box and enter chambers, one of which supplies cool water under pressure and the other of which receives the heated discharge water, Fig. 45.

Admission valves are kept cool by the cool entering mixture, and where practical to let this cool mixture impinge on the exhaust valve it aids in maintaining the latter at a safe temperature. The cylinder jackets are carried as near as possible to and around the valve seats. Exhaust valves for large engines are generally cast hollow and are water cooled.

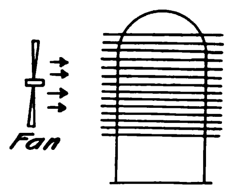


FIG. 46.—Air-Cooled Cylinder.

Air Cooling.—This system is not used as extensively as water cooling. A few automobile and aeroplane engines and all motorcycle engines are air cooled. The cylinder is cast with a number of fins or webs on its outside surface to increase the radiating surface. A fan is installed to increase the air circulation as shown in Fig. 46. Fuel economy at moderate horse-power and speed is better than in the water cooled system, due to the higher cylinder temperatures, but as the engine becomes heated the developed horse-power falls below that which would be developed for given cylinder dimensions. As the cylinder dimensions increase it becomes more difficult to carry off the heat fast enough and there is a practical limit to the size cylinder that can be air cooled. Fig. 47 shows the method of air cooling the Franklin automobile motor. Air is drawn through a trunk line by a

blower in the fly-wheel casing. The cylinder fins are vertical and enclosed in vertical casings that form part of the trunk line; cooling air passes from top to bottom of the casings along the cylinder fins.

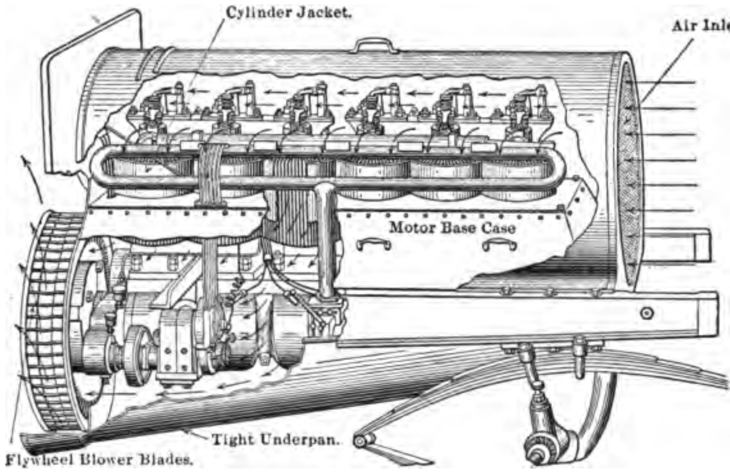


FIG. 47.—Franklin Air-Cooling System.

LUBRICATION.

The external lubrication of an internal combustion engine presents no novel features and requires no comment, but the internal lubrication of the cylinder, piston, etc., is vital to the safety of the engine. A steam cylinder lubricates itself by condensation of steam on the cylinder walls, but, due to the intense heat in the cylinder of an internal combustion engine and due to the high piston speed, it is necessary to have a film of oil between the piston and the cylinder walls at all times.

Kind of Oil.—Oils for lubricating cylinders of internal combustion engines should have the following characteristics:

First: They should be well refined mineral oils; that is, they should be free from acid, alkali, tarry matter, suspended matter, free sulphur and resinous bodies or bodies which are removed by filtering through animal charcoal.

Second: They should have sufficient body to maintain a lubricating oil film or seal between the piston and the cylinder walls, thus insuring perfect lubrication of the pistons and cylinder walls and preventing escape of gases past the pistons and rings.

Third: The oil should be resistant to heat and oxidation to such a degree as will insure good lubrication at high temperatures and will not form a hard carbon deposit in the cylinders.

Fourth: The oil should not become solid at temperatures to which the engine is exposed.

In general, animal and vegetable oils are not suitable for the lubrication of cylinders of internal combustion engines; when exposed to high heat, they decompose, produce acids and deposit excessive carbon in the combustion chamber. Castor oil, however, is used to some extent as a lubricant for internal combustion engines because of its adhesive nature, its property of keeping its body well at high temperatures and its insolubility in gasoline. The choice of a proper lubricating oil for an internal combustion engine is one which requires considerable study for each type of engine, and to arrive at a satisfactory selection it is necessary to consider the bore and stroke of the engine, the materials of which the piston and cylinder are composed, the clearance between piston and cylinder walls, the compression and speed of the engine, the design of the piston and the temperature which is attained by the oil during the operation of the engine.

Viscosity.—The quality of an oil that gives a comparative measure of the friction generated is its *viscosity,* which may be defined as its resistance to flow. The viscosity requirements of an oil are influenced by the tightness of the piston rings. If tight, a light oil will give good results. If badly worn or loose, a heavy oil becomes necessary. If the oil is too light, much of it will be drawn past the piston rings on the suction stroke. Likewise on the compression stroke some of the gaseous mixture from the carburetor will leak past the piston rings, and, condensing in the crank case, will tend to make the oil still lighter. This action is cumulative.

The flash point of an oil is the temperature to which it must be heated in order that the vapors given off will give a slight explosion when a small flame is held immediately over the oil. The *fire point* is the temperature (approximately 50° above the flash point) to which the oil must be heated in order that it will take fire and continue to burn when a flame is applied. It is important that the flash point be higher than the temperature of the inner surface of the cylinder, which is about 270° F. if the water in the jackets is at the boiling point. All motor oils have a flash point above 300° F.

Lubricating oil does not burn very easily or very fast, and the time given for it to burn in a motor cylinder is very short. At high speeds this time is a small fraction of a second. It would therefore appear that a flash point of 300° F. is sufficiently high for almost any water cooled motor; it should be sufficiently high for Diesel engines except in unusual cases. Air cooled motors might in some cases require a higher flash point.

The *cold point,* which is the temperature at which oil freezes, should be sufficiently low to insure that no difficulty will be encountered at the temperatures to which the crank case will be exposed.

Carbon Deposits.—Much misinformation has been published on the subject of *carbon deposits.* What is ordinarily called carbon in cylinders nearly always contains other matter in varying quantity. Rust and small iron particles are nearly always present. In automobile motors a large percentage of dust (silica) is generally present, and in marine motors and Diesel engines salt is a common constituent.

The causes of carbon deposits in cylinders are, briefly, incomplete combustion of the fuel and partial volatilization or decomposition of the cylinder lubricant to heavier hydrocarbons or even free carbon. Much carbon will pass out with the exhaust, but such part as deposits in the cylinder will be hardened under the intense cylinder heat.

Small two-cycle motors can be successfully lubricated by mixing lubricating oil with the gasoline in the tank, in the proportion

of about one pint of oil to five gallons of gasoline. In this method of lubrication the oil must vaporize in the carburetor and be carried with the gasoline vapor into the cylinder where it will condense on the walls, and, when choosing an oil for this, attention should be paid to the characteristics governing its vaporization.

Lubricating Systems.—Internal combustion engine lubricating systems may be divided into three general classes:

1. *Splash systems.*—This class is more commonly applied to the lubrication of internal combustion engines than any other, and is largely used for lubricating automobile motors. Oil is maintained in the crank case at sufficient height for the crank or a small lug on the connecting rod to dip into it at each revolution of the engine, throwing the oil up on the cylinder walls, where the piston spreads it evenly over the surface. Some splash systems employ a pump in addition, to keep the oil at a certain level in the crank case or troughs into which the cranks dip.

2. *Force feed systems.*—The oil is pumped to all moving parts of the engine under pressure, in lubricating systems of this class. From a tank in the base of the engine, commonly called the "sump tank," the oil is pumped through pipes to the crank bearings and thence through the hollow crank shaft to the crank pin bearings. The cylinders obtain lubrication through the wrist pins, which are hollow, and which receive oil from a duct fastened to the connecting rod. The lubricating systems of heavy duty stationary engines, high speed marine engines, and aeroplane engines are generally of the force feed type.

3. *Mechanical feed systems.*—The most general form of mechanical feed employs a lubricator mounted on the engine and operated by means of a belt, eccentric or other driving device. The lubricator generally consists of a series of small pumps, the number depending on the size of the engine, arranged in an oil tight tank or box and driven by a common shaft. The oil is fed into ducts, whence it flows by means of gravity to the moving parts of the engine. The rate of feed is regulated to about equal the rate of consumption, as none of the oil is regained and

pumped over. Mechanical feed systems are commonly employed in the lubrication of two cycle marine engines.

The Detroit Mechanical Lubricator, shown in Figs. 48 and 49, consists of a number of pumping units, all actuated by the same drive shaft, each unit supplying oil by a pipe to an engine part. Each pumping unit consists of a double plunger valveless pump. The oiler is driven by belt or gearing from the engine, and the speed at which it pumps is proportionate to the engine speed.

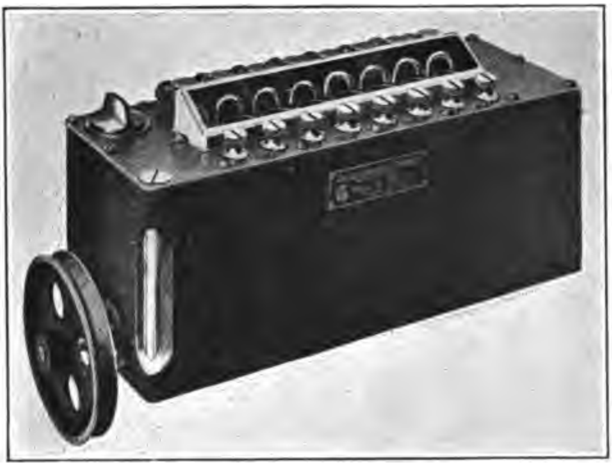


FIG. 48.—Detroit Eight-Feed Oiler, Belt Drive.

Operation, Fig. 49.—The upper piston *B,* driven through the bell crank yoke *E* by the eccentric *G,* lifts the oil from the reservoir and discharges it from the nozzle *N.* The amount of oil discharged is regulated by the adjusting button on the cover, this button having at its lower end the cam *A* which controls the

throw of the piston *B*. The lower plunger *C* takes the oil from the pocket in the sight feed chamber under the nozzle *N* and forces it to the point to be lubricated through the tube *O*.

This forcing plunger *C* is driven by the eccentric *F* through the yoke *D*. The bell crank yoke *E* and the straight yoke *D* give to the pistons an alternate movement, each being substantially at rest while the other is passing through its 90° of most rapid travel. A port in each piston controls the passages to the other so that each becomes, without additional mechanism, a mechanically operated valve for the other.

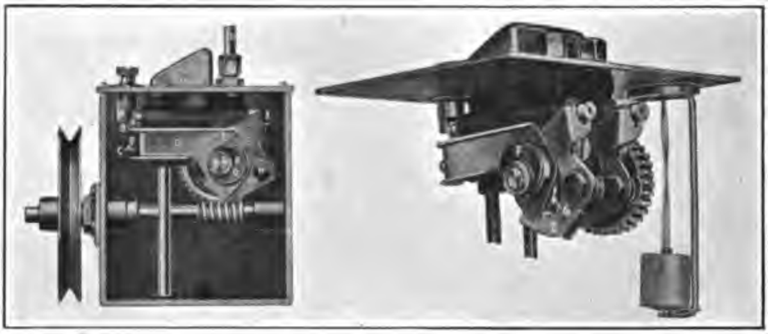


FIG. 49.—Details of Detroit Forced-Feed Oiler.

The eccentric *G* is driven by the eccentric *F* and, when the engine is running ahead, they are in the same position on the eccentric shaft. When the engine is reversed, however, eccentric *G* remains stationary until *F* has advanced 180° in the opposite direction, where it is again picked up and driven in the new direction by *F*. By this simple method the passages, ports and plungers are made to automatically and instantly respond to a change in the direction of drive without adjustment of or interruption to the flow of oil.

CHAPTER VIII.

GOVERNING AND INDICATOR CARDS.

Governing.

Internal combustion engine governing is a more complex proposition than steam engine governing. In the latter case the medium of power, steam, is stable, and for a constant pressure a given governor position will always give the same cycle, hence constant power. On the other hand, the working fluid in an internal combustion engine is far from stable. This medium consists of the gas resulting from the chemical reaction when fuel and air are mixed and ignited in the engine cylinder. Thus it is apparent that for a given fuel the stability of the internal combustion engine medium depends upon the accuracy and variability of mixture, degree of stratification of the charge, and variations in ignition. The perfection of agents to keep these variants within reasonable limits has made possible the application to internal combustion engines of governors which confine the speed fluctuations to small limits.

As in the steam engine, the governor must fulfill two essentials, viz.: It must automatically control the speed as far as possible, and it must be isochronal in the sense that under varying loads it will make the engine perform its cycles in equal times.

The mechanical form of the governor varies as in the steam engine, being of such forms as the fly-ball, inertia, and vibrating types, etc. The systems employed are:

1. The hit and miss system.
2. Throttling the mixture.
3. Varying the quality of the mixture.
4. Varying the point of ignition.
5. Throttling the exhaust.
6. Combination systems.

Governing by the Hit and Miss System.—In one of its forms this was the earliest system employed extensively to regulate internal combustion engine speed. It effects this regulation by omitting an explosion when the speed exceeds that desired. When running at the required speed the cycles follow each other at equal intervals; if anything disturbs this equilibrium, so as to increase the speed, the governor acts and prevents an explosion (causes a "miss") on the following cycle. This miss reduces the speed and the governor acts in the opposite direction, causing the explosions to recur. The greater the excess speed, the greater will be the proportion of "misses" to "hits" until equilibrium is again restored. There are three varieties to this system:

1. Keeping the fuel valve closed so that only air is drawn into the cylinder during the miss cycle.
2. Keeping the inlet valve closed, thus preventing admission of both air and fuel.
3. Keeping the exhaust valve open, thus destroying suction action on the admission stroke of the cycle.

The mechanical operation of the first two methods is the same, the only difference being that in the first case the governor acts upon the fuel valve and in the second case it acts upon the admission valve. Fig. 50, called the pick-blade governor, illustrates this method. *A* is the fuel or admission valve. *B* is a bell crank lever which actuates the valve, opening and shutting it during the regular cycle. This bell crank lever is in turn actuated by the cam *C* on the countershaft. The pick-blade *D* acts as the push rod between the valve stem and the lever *B* during a regular cycle. This pick-blade is connected by rod *E* and bell crank *F* to a collar *G* on the governor *H*. The governor is run by the main or countershaft so that its speed is proportional to that of the engine. When the pick-blade engages the valve stem it is in position for running at the desired speed. If this speed is exceeded, the governor balls fly outward, raising the collar *G*. This causes the pick-blade to move to the right as shown and disengage the valve stem entirely. During the next cycle and until

the speed is reduced to the normal, the pick-blade does not engage the valve stem and the valve does not lift. This operation causes misses. When the speed is reduced the required amount, the balls of the governor assume their original position, the pick-blade again engages the valve stem, and the original conditions are resumed.

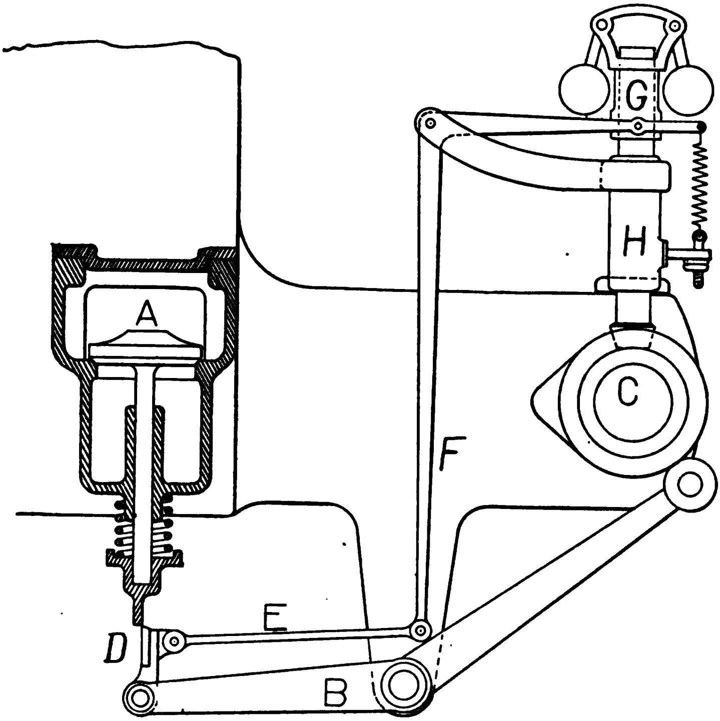


FIG. 50.—Pick-Blade Governor. Governing by the "Hit and Miss" System

The system of governing by keeping the exhaust valve open is often applied to engines that have an automatic spring loaded admission valve. By applying the governor to the exhaust valve this can be kept open when the speed exceeds that desired, and

with this open no vacuum is created on the suction stroke and hence no fresh charge is drawn in. The result is a miss on the following cycle. When normal speed is again reached, the exhaust valve is released and functions as originally.

It is obvious that this system is open to many objections. In a four cycle engine the omission of a working cycle will cause an appreciable variation of the speed even with a large fly-wheel, and if the load is suddenly increased just after the miss cycle, this reduction becomes objectionably large. After the idle cycle, the first impulse is stronger than normal due to the cylinder being well scavenged during the miss cycle. An engine employing the hit and miss system requires a heavy fly-wheel to produce a reasonably uniform angular velocity in the crank shaft. This system is unsuitable for work requiring close regulation of speed, such as electric lighting, etc. Its advantages as a system are its mechanical simplicity and its ability to run on the economical quality of mixture without variation.

Governing by Throttling the Mixture.—A more efficient system of governing than the foregoing is that of throttling the normal mixture so that a smaller quantity of the charge is drawn into the cylinder, but the *proportions* of that charge are unchanged. The governor operates the main throttle, which is generally placed in the admission line between the carburetor and the engine. The advantages of this system are fuel economy and the fact that the engine can work on a constant mixture and receives an impulse every cycle. The pressure in the cylinder is reduced by throttling, due to both reduced fuel supply and to consequent decreased compression. By keeping a constant quality the danger of ignition failure is reduced.

When this system is used the engine is designed for a very high compression at full power so that with a reduced amount of fuel the remaining compression will enable a good thermal efficiency to be attained. The advantages of this system has caused a tendency for its general adoption for many uses, wherever the variation in load does not reduce the charge below the limit of ignition.

Governing by Varying the Quality of the Mixture.—For a given quantity of mixture the initial pressure obtained will vary with the proportion of fuel and air in the mixture. This is the principle of variable quality governing. The governor may act upon the fuel valve, varying the amount of fuel per cycle while the amount of air remains constant, or may act upon the air valve, varying the amount of air per cycle, the fuel valve being automatic. The result in either case is to impoverish the mixture when the speed exceeds that for which the governor is set. It has the advantage that, although the total charge of fuel and air may vary in quality, the *quantity* admitted each cycle is constant, therefore the compression is the same for varying loads. Theoretically, the result should be equal thermal efficiencies for all loads but, practically, the fuel consumption rapidly increases as the load decreases.

The reason for decrease of thermal efficiency with the load under this system of governing is that as the mixture becomes rarer ignition becomes more difficult and combustion much slower, resulting in greater heat losses to the cylinder walls. If carried too far the mixture may become so rare that it cannot be ignited.

Governing by Varying the Point of Ignition.—The ignition systems of nearly all internal combustion engines are so fitted that the point in the engine stroke at which ignition takes place may be varied. The electrical systems particularly lend themselves to this form of regulation. Thus the charge may be ignited before the piston reaches the end of the compression stroke ("advanced spark"), at the end of the compression stroke when the compression is a maximum, or on the expansion stroke beyond the dead center ("retarded spark"). It is evident that the maximum impulse is obtained if combustion takes place when the compression pressure is a maximum. If ignition takes place after the piston has passed the dead center and started on the combustion stroke, then the compression being less than maximum, the power obtained is less than full power. If the charge is ignited and combustion takes place before the piston has passed the compression stroke dead center, it is evident that the piston will be driven

backwards ("back fire") unless the fly-wheel inertia is sufficient to carry the piston over the dead center.

This system is used extensively in marine engines as well as in motor vehicles. Its use facilitates hand starting by preventing "back firing." To start, the ignition is retarded well past the dead center. After the engine is running the spark is advanced until ignition takes place a little ahead of the dead center. The reason for this is that, combustion not being instantaneous, if the charge is ignited at the proper point before the piston reaches the dead center, the maximum pressure of combustion will occur at the end of the stroke, and the expansion will thus be a maximum.

The proper ignition point is found as follows: Advance the spark until a distinct "knock" is heard. Then retard the spark until this knock just disappears.

Governing by Throttling the Exhaust.—If the exhaust be throttled it will produce a braking effect or back pressure during the exhaust stroke. This effect is particularly noticeable in a single cylinder engine. Another effect of throttling the exhaust is to leave some of the products of combustion in the cylinder which prevents a full charge being drawn in on the suction stroke. Moreover, the reduced charge is diluted by the exhaust gases present. This system being highly inefficient is little used.

Combination Systems of Governing.—Although not general, combination systems are sometimes used. Some American Crossley engines govern by the variable quantity or quality method at high loads and by the hit and miss system at low loads. Some engines govern by the variable quantity method at high loads and by the variable quality method at low loads, and *vice versa.* A thermally correct method is that advanced by Letombe. This consists of increasing the time of opening of the inlet valve, but decreasing the lift of the fuel valve as the load decreases. In a sense this is quantity regulation, but the increased opening of the inlet valve increases the total charge, and thus the leaner mixtures are more highly compressed than the richer mixtures that are used at the higher loads. Attempts have been made to vary the compression space so that compression can be made constant for all loads, but no practical method embodying this principle has been devised.

Indicator Cards.

The theoretical four cycle engine indicator card with variations is shown in Figs. 51 to 56. Fig. 51 illustrates a theoretically perfect card. All the strokes and periods in the cycle are marked, and starting at any point the cycle can be easily traced. The

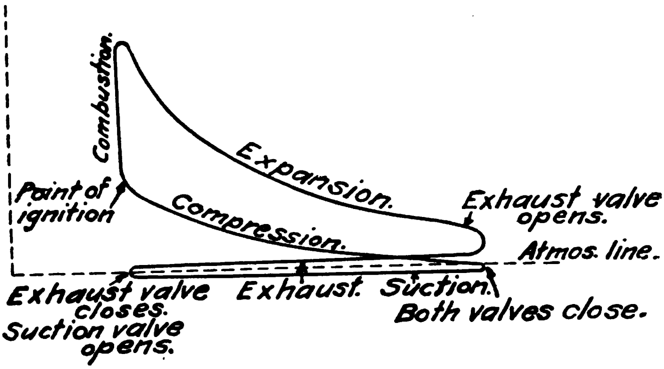


FIG. 51.—Normal Indicator Card.

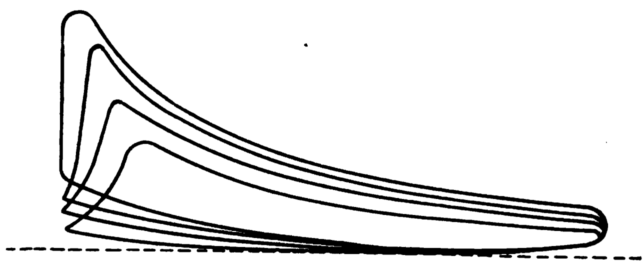


FIG. 52.—Effect of Throttling the Normal Charge.

lower loop is somewhat exaggerated in all figures. It is apparent, when tracing the cycle, that the lower loop is traced in the opposite direction to the upper loop. This indicates loss of work and the work represented by the lower loop must be subtracted from that represented by the upper loop to get the net work of

the cycle. The atmospheric line is shown dotted in each figure. *In cards 52 to 54, inclusive, the suction and exhaust strokes are omitted for simplicity of discussion.*

Throttling.—Fig. 52 shows the effect of throttling the normal charge. A number of cards are superposed to illustrate the point that as the charge is throttled the card becomes smaller, showing a decrease in total work. Throttling decreases the

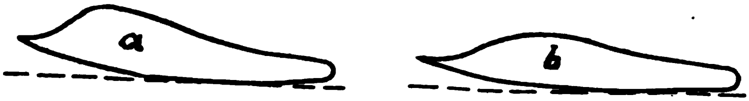


FIG. 53.—Effect of Retarding Ignition.

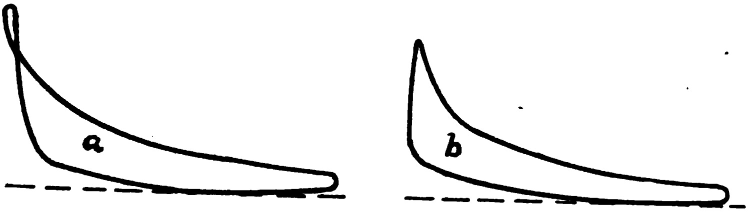


FIG. 54.—Ignition Too Early.

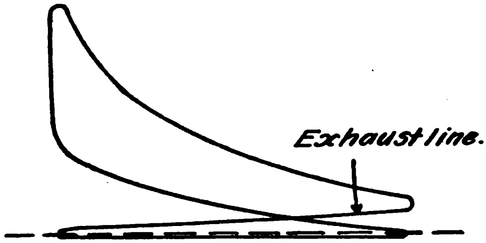


FIG. 55.—Faulty Exhaust.

amount of mixture that is drawn in each cycle. As the charge is reduced, the compression space being the same, the compression pressure is lowered, and, as a direct result of this reduced pressure, combustion is slower. These points are indicated in the card by the lowered compression line and the sloping combustion line, respectively.

Retarded Ignition.—Two cards are shown in Fig. 53 to illustrate the effect of retarding ignition. Cards *a* and *b* were taken with ignition timed respectively 5 and 10 per cent late. If ignition takes place after the piston passes the dead center this is indicated on the card by the combustion line returning along the compression line until the point of ignition is reached. The later the ignition the lower will be compression at the point of ignition, therefore combustion will be slower and the combustion line will be lower.

Advanced Ignition.—Cards *a* and *b,* Fig. 54, are taken from an engine that has the spark advanced so far as to ignite respectively 20 and 12 per cent early. Ignition in card *a* takes place before the end of the compression stroke, maximum pressure is attained before this stroke is completed, and the result is a loop in the upper part of the card, which loop being traced in the reverse direction to the general direction of the cycle represents loss of work.

Faulty Exhaust.—Fig. 55 is a card taken from an engine with a faulty exhaust. This fault may arise from a clogged exhaust, the exhaust valve or passages may be designed too small, the exhaust valve may be incorrectly timed, the exhaust passage may be so long as to create a back pressure or may have sharp bends in it. Any cause that would interrupt the exhaust enough to create a back pressure will be indicated on the card by an abnormal rise in the exhaust line. This rise is exaggerated in the figure.

Faulty Admission.—If admission is partly choked the suction line will be lower than normal, Fig. 56. This may be caused by too small an admission valve, admission passages too small or too many bends in the passage, inlet choked, or not enough lift to admission valve; if a spring loaded admission valve then the spring may be too strong, thus decreasing the lift.

Two Cycle Card.—Fig. 57, the indicator card of a two cycle engine, consists of two separate diagrams. The upper diagram is taken from the engine cylinder and the lower diagram from the crank case. These are traced in opposite directions (the upper

card in the forward direction), consequently the work indicated is the difference of the two diagrams.

From the foreging examples it can be readily seen how important is the information that can be gained from good indicator cards. All faults of internal working may be obtained from well

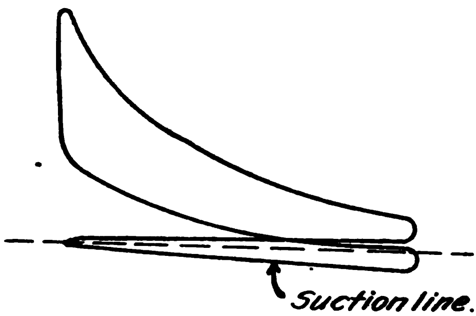


FIG. 56.—Faulty Admission or Suction.

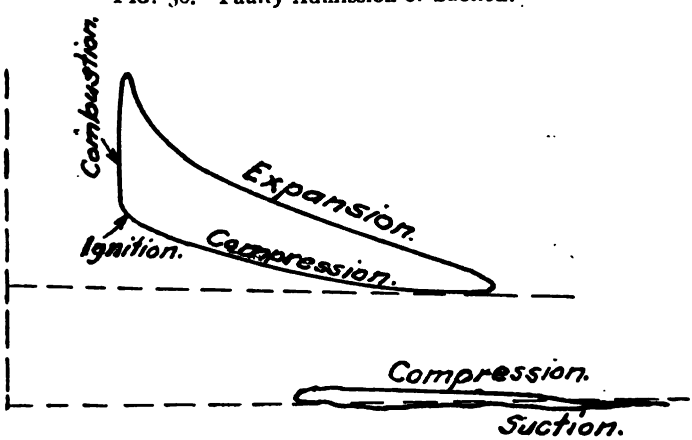


FIG. 57.—Two Cycle Engine Card.

taken cards. They give data on performance, and valve settings can be checked by them. Manufacturers, however, are more interested in the brake horse-power than in the indicated horse-power, and all factory tests are made for the former by means of a dynamometer, see page 90.

Indicators. The Manograph.—The power of an internal combustion engine may be measured in a manner similar to that employed in measuring the power of a steam engine. That is, indicator cards are taken to obtain the mean effective pressure acting, and this, with the number of revolutions and the engine dimensions, gives the necessary data for use in the horse-power formula. For slow moving, heavy duty engines, indicators similar to steam engine indicators may be used. These indicators have external springs. However, they are impractical for high-speed engines because of the inertia of the parts, the liability of the cords and other flexible parts to stretch, and the frequency with which the springs break. Indicator cards for high-speed engines are taken by an ingenious device called the manograph. This

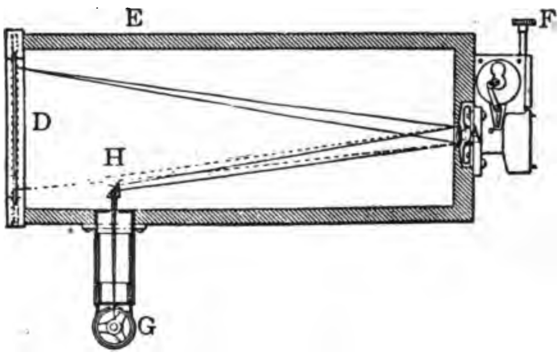


FIG. 58.—The Manograph, Cross Section.

indicator overcomes the inherent difficulties of the ordinary piston type of indicator by substituting a beam of light for the pencil of the ordinary indicator. This beam traces a card on a ground glass screen or a photographic plate; the former is used for casual inspections of the engine's performance and the latter is used when a permanent record is desired.

The manograph, which can be seen in the Naval Academy laboratory on the Mietz and Weiss engines, consists of a light-tight box mounted on a tripod. At one end of this box, Figs. 58 and 59, a mirror N is so mounted that it is capable of rotation

about two axes at right angles to each other. An acetylene burner *G* on one side of the box, shining through a diaphragm, reflects a beam of light through the prism *H* to the mirror *N*. The beam is again reflected from the mirror *N* on to the screen or plate *D*. The mirror *N* is given two motions, one in proportion to the piston motion and the other at right angles to the first in proportion to the pressure on the piston at any simultaneous piston position. As the mirror moves in two directions the beam of light will follow a path which is compounded from two rec-

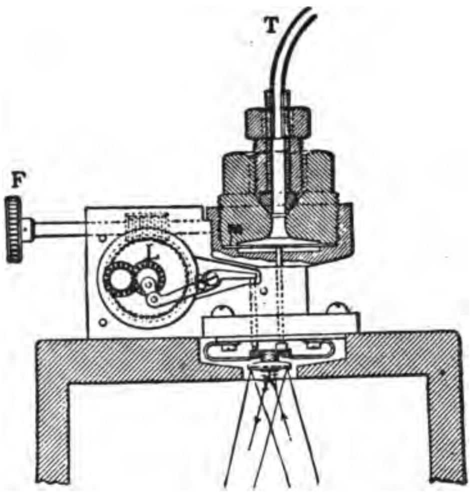


FIG. 59.—Details of Manograph.

tangular co-ordinates, one proportional to the piston position and the other proportional to the simultaneous piston pressure. In other words, the beam will trace a card on the screen similar to a card obtained by an ordinary indicator, but, since the moving part in the manograph is the beam of light which has no inertia, the inaccuracies, due to inertia of parts, etc., are eliminated.

Motion proportional to pressure is given the oscillating mirror as follows: The mirror is mounted on springs, Fig. 59, which tend to keep it parallel to the screen. The tube *T* communicates with the engine cylinder and allows the cylinder pressure to act

on the diaphragm M. This diaphragm is connected with the mirror N by a pin offset from the mirror center. It is obvious that the mirror will be rotated by this pin an amount proportional to the pressure on the diaphragm, which is the cylinder pressure. The tube T can communicate with the different cylinders on a multicylinder engine by means of a multiway cock.

Motion proportional to the piston travel is given the mirror N as follows: The flexible shaft R (Fig. 60) connects the crank shaft center to L and rotates with the shaft. By means of the gear L and a pin, which is 90° on the mirror from the other pin, motion proportional to the piston travel is imparted to the mirror, for the mirror receives one complete oscillation each revolution of the engine.

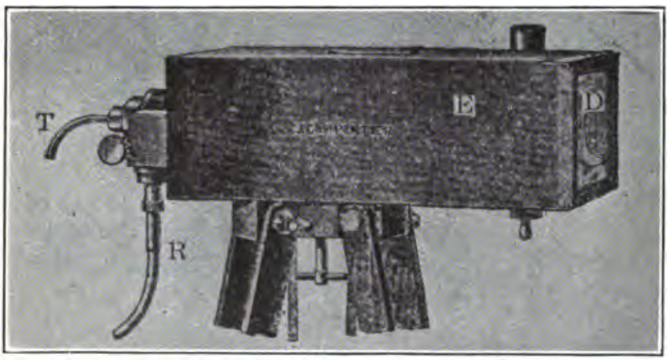


Fig. 60.—The Manograph.

The angular motion of the mirror is very small. The thumb screw F is for the purpose of establishing synchronism between the engine crank and the small manograph crank that actuates the pin c.

Horse-Power.

Indicated Horse-Power.—The average or mean height of the indicator diagram, measured on a scale corresponding to the

indicator spring, gives the ***mean effective pressure*** acting on the piston, and this constitutes the P_e of the horse-power formula:

$$I.H.P. = \frac{P_e \times A \times L \times N_e}{33,000} \text{ where}$$

P_e = mean effective pressure from card.
A = area of piston in sq. in.
L = length of stroke in feet.
N_e = number of power impulses per minute.

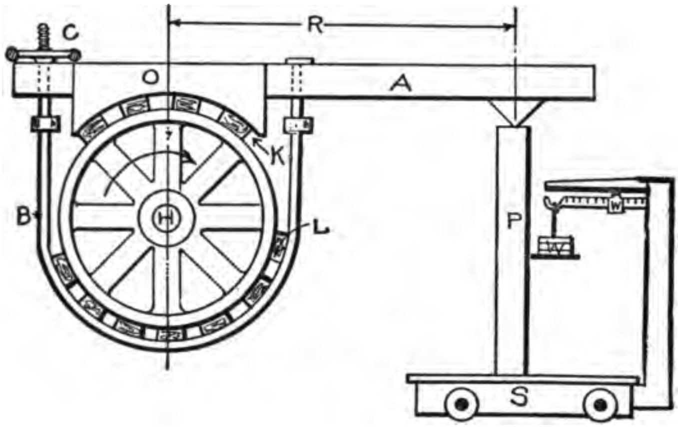


FIG. 61.—Prony Brake.

Brake Horse-Power.—Dynamometers are used for measuring the brake horse-power of engines. This instrument takes a variety of forms, the most common of which is the Prony Brake. It is shown in its typical form in Fig. 61. *H* is the fly-wheel of the engine, turning as indicated by the arrow. The lever *A* rests on the wheel *H* as shown. *K* and *L* are wooden blocks, which are pressed against the face of the fly-wheel by the tension produced by an adjustable strap *B* and the weight of the yoke *O*, thus applying a friction load to the fly-wheel as desired. The pressure due to the energy absorbed by the brake is carried by the lever *A* and post *P* to the platform scales *S*, which are adjusted to just balance the load.

If R = Length of the brake arm or lever R in feet.
N = Revolutions per minute of the fly-wheel.
W = Net weight in pounds at distance R, measured by scales.

Then the brake horse-power would be $\frac{2\pi RNW}{33,000}$.

The value $\frac{2\pi R}{33,000}$ is called the *brake constant*, and, for the same brake, is the same for all loads.

Before starting a test a *zero reading* of the brake is obtained, since the scales weigh not only the pressure due to the friction load on the lever, but also the weights of the brake and post *P*. To determine the zero reading, the strap *B* is loosened and the fly-wheel is turned by hand in one direction and the scale weight is noted. Then the fly-wheel is turned in the opposite direction and the scale weight is again noted. The friction between the loosened brake band and the fly-wheel is assumed the same for both directions of rotation. By adding these two weight readings together and dividing the result by two, the mean weight of that part of the brake that rests on the scales is determined This is the *zero reading*.

CHAPTER IX.

OPERATION, TROUBLES, AND REMEDIES.

To Start and Stop a Motor.—Small motors may be started by hand by giving a few turns to the fly-wheel or to a crank fitted to the crank shaft, but the larger engines require an auxiliary starting mechanism. Some engines are fitted so that they may be run by compressed air for a few revolutions until the first explosion is obtained. Another method is to introduce a charge of mixture into a cylinder by a pump, and then to fire this charge by the igniter or a detonator. With this latter method, care must be taken that the piston is on the expansion stroke, for, if it is on the compression stroke, a back-fire will result and the engine will start in the reverse direction; this causes undue stress on the parts and may even fracture the main or crank shaft.

In most engines the point of ignition is capable of adjustment. In this case retard the spark so that ignition will occur after the crank passes the dead center. See that the ignition circuit, oiling gear and cooling water are in order and turned on. Open the throttle, fuel valve to carburetor if installed, prime the cylinder and open the relief cocks on the cylinders, if necessary. Give the engine a few turns by the fly-wheel, if small, or the starting device, if large, and, if everything is in order, the engine will start. Opening the relief cocks relieves the compression and makes cranking easy; on the other hand, relieving the compression makes ignition more difficult. The behavior of the engine at hand will govern this point. After the engine is started, adjust the ignition to the proper lead, close the relief cocks if open, see that the oil and water are working properly, and adjust the mixture if necessary. These general instructions may be modified for different types of engines. If an engine is to stop but a few moments, the ignition circuit may be broken, if of the jump spark

type with battery and coil. The few revolutions due to inertia after the spark is cut off will leave the cylinders charged with the mixture. By again closing the ignition circuit a spark will jump in the cylinder that has its piston in the firing position, and, if the mixture is still in combustible form, the engine will start without cranking. This is called " starting on spark."

To stop the engine, close the thottle, break the ignition circuit, and close the fuel valve. If exposed to freezing weather, drain engine jackets and connecting pipes. Although it has been recommended that the oil supply be shut off before the engine is stopped in order that the surplus oil may be carried out with the exhaust, the author is not in agreement. If the oil supply is properly regulated, there will not be enough surplus to cause serious clogging in the cylinder or valves, whereas it is obvious that serious results may occur, if the engine is started without turning on the oil supply (as might easily happen, if other than the regular hand started the engine). Wrecks from this cause are not infrequent. In modern practice, especially where the splash system is used, the oil supply is left turned on at all times. This does not apply to heavy-duty motors having special feed systems.

Failure to Start.—Should the motor fail to start, the trouble can only be found by a man conversant with the interrelation of the parts of the machine and their relative functions, and " trouble hunting" resolves itself into an investigation of the different integral systems of the motor. Of course many causes of non-starting are apparent from the behavior of the machine, and an experienced hand will generally have little trouble in finding the defect. However, occasionally a defect will baffle even an expert until he has thoroughly overhauled and analyzed the motor.

When investigating non-starting, divide the machine as follows:

1. Ignition system.
2. Fuel system.

Non-Starting Due to Faulty Ignition.

First look to the spark. It may be too feeble to ignite the mixture or may not occur at all. In this case first test the battery. If this is found in good condition, test the line up to the plug for broken wires, short circuits or poor contacts. Finally look at the plug. It may be too foul for the spark to bridge, the points may be too far apart, or the insulation may be defective.

If a good spark is present at the plug, then it may be taking place at the wrong part of the cycle, due to the timer being out of adjustment. This discrepancy is made good by so adjusting the timer that the spark will occur at or just beyond the end of the compression stroke. If the spark is strong enough for ignition and is properly timed, then the trouble will be found under the second head.

Non-Starting Due to Fuel Supply.

The tank may be empty or the fuel valve closed. Although this sounds childish, many operators have wasted much valuable time trying to start under these conditions. The feed pipe may be clogged. Often waste or other foreign matter find their way into the feed pipes through the tank. The throttle or the air valve may be stuck. Defective adjustment of the air valve may result in a non-combustible mixture. The carburetor may be out of order. A leaky needle valve, resulting in a flooded carburetor, is a frequent source of trouble. The compression may be defective, due to leaky or broken piston rings or valves. This is evidenced by the reduced resistance encountered when cranking the engine. A broken valve stem or loose valve cam, which does not show at once, may cause a valve to become inoperative. In a new installation the tank may be too low to supply a gravity feed, or the lead of feed pipe may be bad.

Common Troubles and Their Causes.

Back-Firing.—This, one of the commonest of troubles, consists of explosions in the passages outside of the cylinder. They

may be located in the exhaust pipe or passages, or in the inlet passage between the carburetor and inlet valve. In the case of exhaust-passage explosions, ignition may be too late. Combustion is incomplete when the exhaust valve opens, and some of the unburnt charge finds its way to the exhaust passage, where it explodes. When governing by the hit and miss system the unexploded charge of a miss cycle may explode in the exhaust passage when the hot exhaust of the next exploded charge comes in contact with it. A mixture which burns so slowly that combustion is incomplete when the exhaust valve opens will have the same effect as late ignition.

Back-firing in the admission passage is more perplexing. A leaky, broken or badly timed admission valve may transmit the combustion within the cylinder to the fresh charge in the admission passage, causing a back-fire there. Another, and very common, cause for this form of back-firing is a too lean mixture. Very lean mixtures burn slowly, and combustion may continue throughout the exhaust stroke until the inlet valve opens, thus exploding the mixture in the inlet passage. A very rich mixture might act in the same manner, but it is more likely to cause a back-fire in the exhaust passage. A loose valve cam may cause back-firing by timing an admission or exhaust valve improperly.

Misfiring.—There are two distinct classes of misfiring, continuous and intermittent. Continuous misfiring of one cylinder of a multiple cylinder engine is a simple problem. The trouble is almost certain to be in the ignition system, because the operation of the other cylinders indicates that the fuel supply is operative as far as the admission valve of the defective cylinder, and were trouble located in the valves of the defective cylinder it would generally be accompanied by back-firing. If the valves are found to be functioning correctly then the ignition system must be overhauled. The system is operative as far as the coil because if it were defective in the battery or primary line to the coil all the cylinders would fail to fire. Among the ignition defects that might cause misfiring in one cylinder are foul or defective plug,

broken wire or bad contacts, or improperly adjusted coil vibrator. These are all easily found by simple electrical tests.

Intermittent misfiring may be caused by improper mixture, weak battery, poorly adjusted coil, broken wires or connections that are in contact intermittently due to the vibration of the engine, dirty sparking device, admission valve, if automatic, not working freely, exhaust valve not closing every cycle, leaky valves and poor compression, or water in the gasoline.

Carburetor explosions have the same origin as admission pipe back-firing.

Muffler explosions have the same origin as exhaust pipe back-firing.

Weak explosions are due to late ignition, weak battery, poor quality of the mixture, insufficient compression, or loss of compression due to leaky or broken piston rings or valves. Overheating may give weak explosions and attendant loss of power due to the dissociation of the mixture to its elements.

Overheating may be occasioned by one of three causes, excess friction due to poor adjustment of bearings, etc., defective circulating water supply, or failure of the lubricating system. The water supply may fail totally or partially due to pump breakdown, clogging of the pipes, closed valve in the line, or sediment on the cylinder walls. When the water supply fails the temperature quickly rises high enough to burn the oil and damage ensues, the piston rings and cylinder walls wear and the piston will ultimately seize. Failure of the oil supply, if not discovered early, results in the same serious trouble. Serious overheating is attended by loss of power, and this is an early indication that should be a warning signal to an experienced man. Sharp clicking, similar to a spark knock, may be the first symptom.

Knocking may be due to mechanical trouble such as loose bearings, etc., or to explosive defects. Under the latter head there are two recognized classes of knocks, "gas knocks" and "spark knocks." A gas knock is caused by the mixture being too rich or by opening the throttle too quickly. It is an infrequent phenomenon. A spark knock is caused by advancing the spark too far. A

slight pre-ignition occurs, and though it is not early enough to cause reversal of the engine rotation, it puts undue stress on the parts and causes a tinny thump. Carbon deposits will cause knocking in the cylinder. Near the end of the compression stroke these become incandescent and premature ignition results.

Crank case explosions in a two cycle engine are caused by a thin mixture or a retarded spark. In either case combustion is not complete when the admission port is uncovered and burning gases come in contact with and ignite the fresh charge in the admission pipe. The explosion transmitted through this pipe to the crank chamber may be a source of much annoyance, for frequently the crank case cover gasket is blown out and must be replaced to keep the case gas tight.

A smoky exhaust indicates too rich a mixture or an excess of lubricating oil. In the latter case the exhaust is black or dark brown, burnt oil vapor being present. In the former case the exhaust is generally hazy and lighter and carries the pungent smell of unburnt fuel.

Lost compression may be due to improper lubrication. An important point that is often overlooked is the fact that the oil film between the piston ring and cylinder forms a packing, and, if this is not perfect, the gas will leak by on the compression stroke. This is technically known as "blowing." Other and more frequent causes of loss of compression are overheating, leaky or broken valves or rings, leaky spark plug gaskets and relief cocks, and scored or worn cylinder walls.

Premature ignition may be produced by advancing the spark too far, too high compression, overheating, overloading the engine, or by incandescent carbon deposits on the piston or cylinder heads. The remedies are obvious. Carbon deposits must be removed periodically. This is generally done by scraping. There are several reliable solutions on the market for this purpose, but none of these will completely remove old carbon.

Carburetor troubles are common and numerous. The needle valve may leak and flood the gasoline chamber. This will cause a very rich mixture, and can be remedied by grinding the valve.

7

The air valve or throttle may become stuck. The auxiliary air valve spring may not be properly adjusted to give the correct mixture at high speeds. Water may accumulate in the float chamber, if present in the gasoline; a drain cock is generally provided to avoid this difficulty. The spray nozzle may clog if there is dirt in the gasoline. Gasoline should be thoroughly strained through chamois before putting it into the tank. This will remove all dirt and water, if carefully done. A thorough knowledge of the carburetor is essential for successful operation of any internal combustion engine.

General.

Pressure Diagram.—The diagrams in Fig. 62 show the effect of multiplying the cylinders of an engine. They are constructed by superposing the cards of a one cylinder engine in the appropriate phase of two successive cycles. Similar diagrams can be made for two cycle engines. The upper line, which represents the pressure acting during two complete cycles, shows 1,080° or six strokes of idle effort during two cycles. The second line, which represents a two cylinder engine, shows that pressure is acting 50 per cent of the time. It is not until the diagrams of six cylinders are combined that an overlapping pressure is obtained.

Long and Short Stroke Motors.—The proportion of cylinder diameter ("bore") to stroke is a problem that has caused more discussion and resulted in less uniformity of opinion than any other subject in the internal combustion engine field. Although no distinct line is drawn, a motor that has a stroke exceeding 1½ times the bore is generally spoken of as a "long stroke" motor, and any having a smaller ratio, as a "short stroke" motor. As the advocates of both types lay claim to every conceivable advantage, the subject will not be discussed here other than to say that increasing the stroke increases the expansion and also the loss by radiation due to the longer contact of the gases each stroke with the cylinder walls. It increases the piston speed; and reducing the bore to maintain the same power, it increases the ratio of

cylinder wall to cylinder contents, hence increases loss by radiation.

The duty for which the motor is designed, the necessary piston speed, power required, weight allowed and initial compression, must regulate the bore and stroke to a large extent.

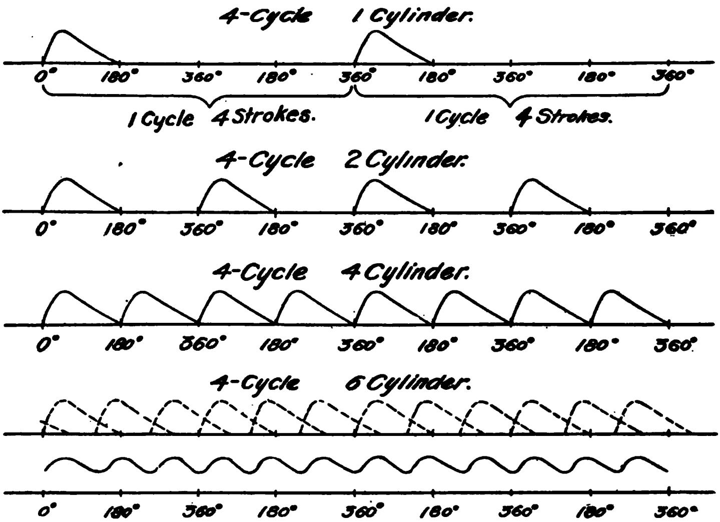


FIG. 62.—Pressure Diagrams, Showing the Effect of Multiplying Cylinders.

Clearance.—The clearance volume is the space enclosed by the piston head, cylinder walls and valve recesses, when the piston is at the beginning of its stroke. The proportion of the clearance volume to the piston displacement is much higher than in the steam engine, because all the medium is present in the cylinder at the beginning of the stroke instead of being admitted during a fraction of the stroke as in the steam engine. This statement does not apply to the Diesel and similar oil engines. Its value depends upon the kind of fuel used, sometimes exceeding 35 per cent. Obviously the higher that the fuel can be compressed, the less clearance that will be necessary.

Scavenging.—Scavenging a cylinder consists of driving out the burned gases before, or simultaneously with, the entrance of a new charge. This is very imperfect with an ordinary four cycle motor, for, at the instant of admission, *all* the clearance volume is full of the burned gas. Those engines which receive the air and fuel separately can be scavenged thoroughly by admitting the air while the exhaust port is still open and driving out the exhaust gases by this air before the fuel valve opens. Two cycle engines require thorough scavenging. A study of the cycle shows that upon this depends the volume of fresh mixture that can be taken into the cylinder, and as the two cycle exhausts just past the center of the expansion stroke, instead of at the end as in the four cycle, scavenging is of more importance in the former case. This is generally accomplished by allowing some of the fresh charge to enter while the exhaust port is still open. A proper design of exhaust will aid scavenging by giving the exhaust gases a high speed, causing a tendency toward a partial vacuum in the exhaust line.

CHAPTER X.

GASOLINE, KEROSENE, AND ALCOHOL ENGINES.

Navy Type Engine.

This two-cycle, three port, gasoline engine, the action of which is described and illustrated on pages 38 and 39, was developed by the Norfolk Navy Yard to meet exacting service in Naval launches after it was demonstrated by years of trial and test that no commercial engine then on the market quite answered Service requirements. All parts are made from standard metal patterns, insuring interchangeability.

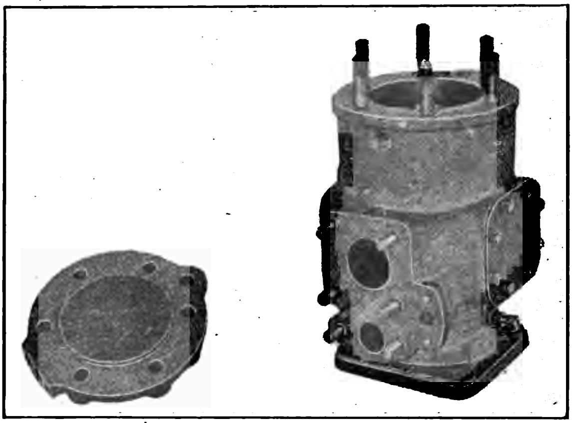


Fig. 63.—Cylinder and Cover, Navy Type Motor.

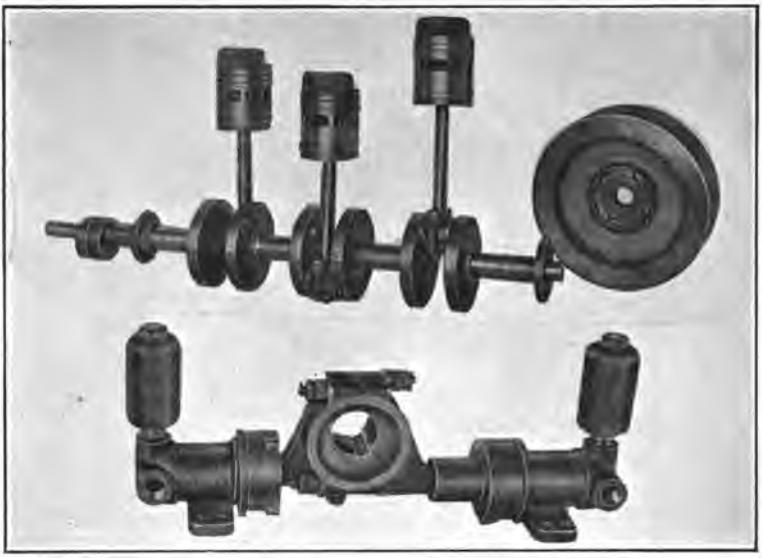
Four models are built, viz.: EE, one cylinder; GG, two cylinder; HH, three cylinder; and KK, four cylinder. They are rated at five brake horse-power per cylinder at 500 revolutions per minute, bore 4½ inches, and stroke 5 inches.

Cylinders are of special, hard, close grained iron, provided with removable heads, which, together with the cylinders, are amply water jacketed. Cylinder jackets are provided with large access plates (Fig. 63).

Pistons are cast of the same material as the cylinders, carefully turned and taper ground, and are fitted with four eccentric rings, three at the top and one at the bottom. Below the latter are two oil grooves (see Fig. 10).

Connecting Rods are drop-forged steel of I-beam section, the crank pin end being fitted with babbit lined, removable brasses, made in halves. The upper end is rigidly secured to the wrist pin, which is of hollow hardened steel (Fig. 10).

Crank Shafts are special carbon steel drop-forgings, machined and ground to .001 inch and are carefully balanced (Fig. 64).



FIGS. 64 and 65.—Crank Shaft, Pistons, Flywheel, Plunger Pumps.

Crank Cases are designed to give the correct crank case compression. They are made in two halves, dividing on the shaft center line. Crank shaft bearings are fitted with removable, babbit-lined brasses, made in halves.

Pumps.—A plunger circulating pump is driven from the crank shaft. A bilge pump of the same construction is supplied with all but the one cylinder engine (Fig. 65).

Lubrication is by crank case splash system and by Detroit forced feed mechanical lubricator, as described on page 75. Grease cups are located at necessary external bearings.

Ignition is of the high tension, jump spark type, using Bosch high tension magneto. The two larger engines use a Dual or Duplex system with battery.

Carburetion.—The carburetor is a Model D, Schebler, described on page 46. The inlet manifolds are of copper. The exhaust manifolds are water jacketed.

The Standard Submarine Chaser Engine.

The Standard Engine for 110-foot submarine chasers, Figs. 66 and 67, built by the Standard Motor Construction Company, is a six cylinder, single acting, four cycle, gasoline engine of 220 brake horse-power at 460 revolutions per minute, bore 10 inches, and stroke 11 inches. It weighs about 30 pounds per horse-power and has a guaranteed fuel consumption of not more than one pint per horse-power hour at full power.

The Engine Frame is built of turned steel stanchions, cross braced, and the bed plate is of cast iron. It has planed web supports for the main bearings.

Main Bearings are split and set in the bed plates. They are of phosphor bronze and provided with oil grooves. The upper caps are recessed in the bed plate.

Cylinders are cast separately of hard close grained iron, with removable heads. Cylinders and heads have large water jackets, the heads receiving circulating water externally, independently of the cylinders. Substantial lugs are cast on the cylinders for bolting to the steel stanchions.

Pistons are of hard close grained cast iron. The wrist pin is secured to the piston; the connecting rod works on the pin.

Connecting Rods are of nickel steel. The upper ends are fitted with phosphor bronze bushing, and the lower ends are fitted with split phosphor bronze bearings.

The Crank Shaft, a one-piece nickel steel forging, has seven point suspension, and six throws arranged at 120° interval.

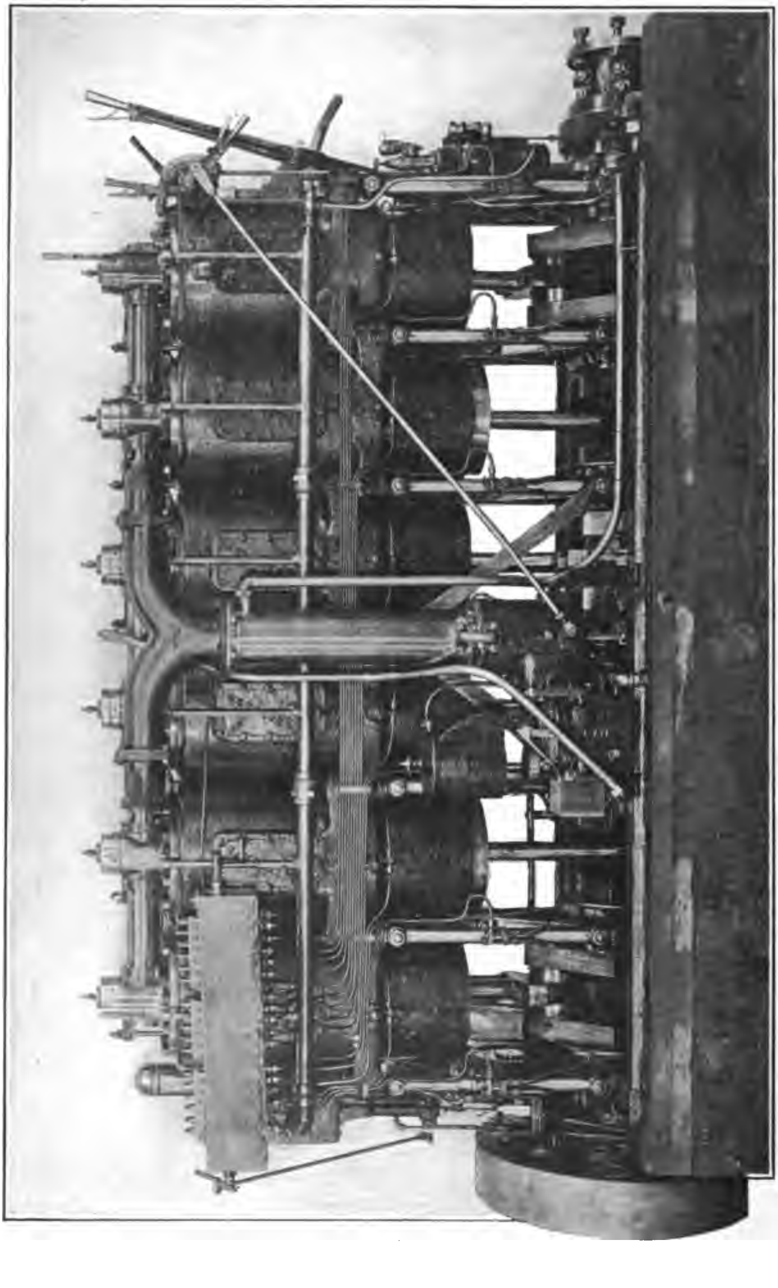


Fig. 66.—The Standard Submarine Chaser Engine.

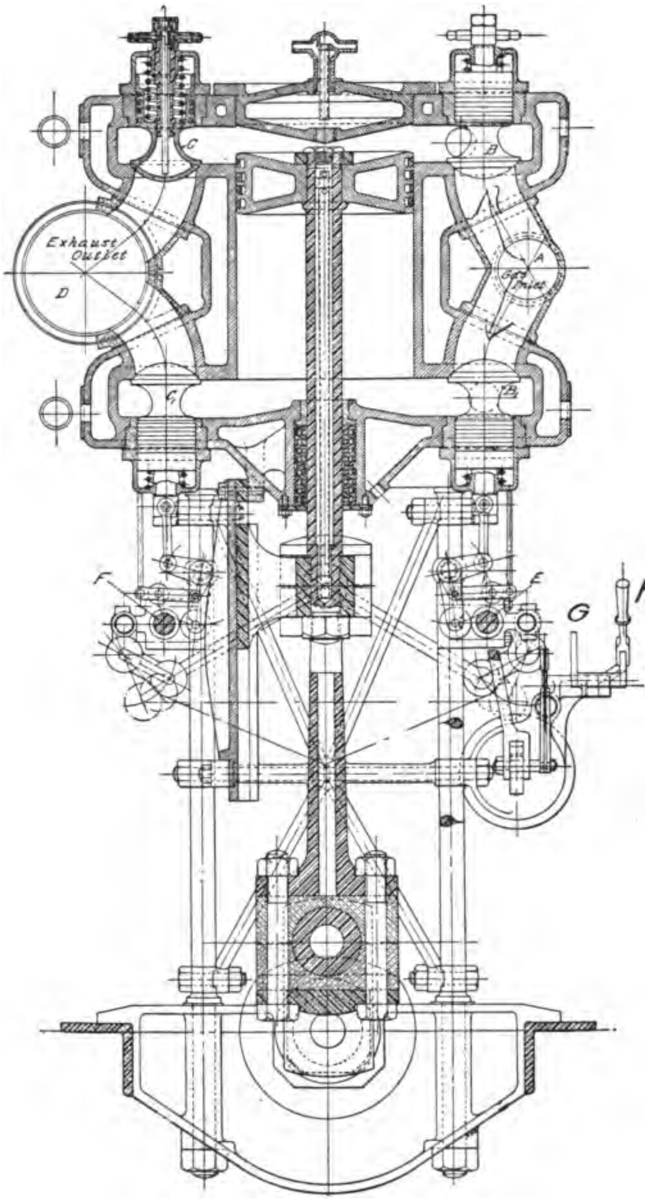


FIG. 69.—Standard Engine.

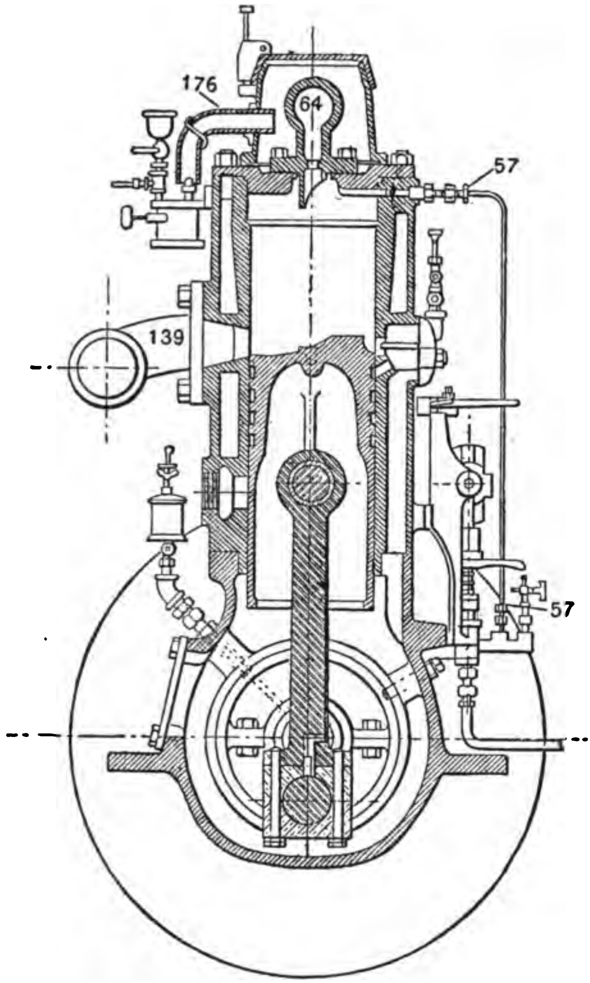


FIG. 70.—Mietz and Weiss Oil Engine.

In Fig. 69, *A* is the gas inlet, *B* the top admission, *C* the top exhaust, and *D* the exhaust outlet. It is apparent that this will operate as a four cycle engine. On the bottom end, B_1 is the bottom admission, and C_1 the bottom exhaust. This end also acts as an independent four cycle engine. *E* and *F* are the cam shafts that operate the admission and exhaust valves, respectively.

The engine is operated by the two levers, *G* and *H*, shown on the front of the engine. *G* is the spark lever. The lever *H* operates a compressed air valve which, in turn, can shift the admission valve cam shaft in the direction of its length. This shaft carries three sets of cams. One operates the admission valves for ahead direction, one for reverse direction, and one set operates air valves in the bottom of the three after cylinders for starting and reversing.

The Mietz and Weiss Marine Oil Engine.

The Mietz and Weiss is a two-cycle marine oil engine that operates on the Semi-Diesel principle, using kerosene, fuel or crude oil. Its fuel consumption is about one pint of oil per horse-power hour at all loads.

Fig. 70 shows a cross section of the engine. The piston is of the trunk pattern fitted with cast iron packing rings. The cylinders are amply water-jacketed; circulation is by a rotary pump driven by gear from the main shaft. Circulating water enters the base of the jacket, is forced up to the top and is led into the exhaust pipe to prevent overheating of the latter. This is a common marine practice.

Fuel is supplied by a pump which is governor regulated so that the amount of fuel supplied is a function of the speed and load. The fuel enters the cylinder by the pipe 57 and encounters the hot bulb 64, which vaporizes and ignites it. Waste gases pass out at the exhaust 139. When the engine is to be started cold the bulb must be heated to dull red heat by an external burner 176. After the first explosion the bulb will retain its heat and the ignition is by a combination of compression and hot bulb.

Lubrication is by forced feed, the oil pump consisting of a plunger worked by a ratchet, the lubrication of the cylinder, piston, crank pins, shaft bearings and connecting rods being absolutely automatic. An engine of this type is installed in the Engineering Laboratory, U. S. Naval Academy.

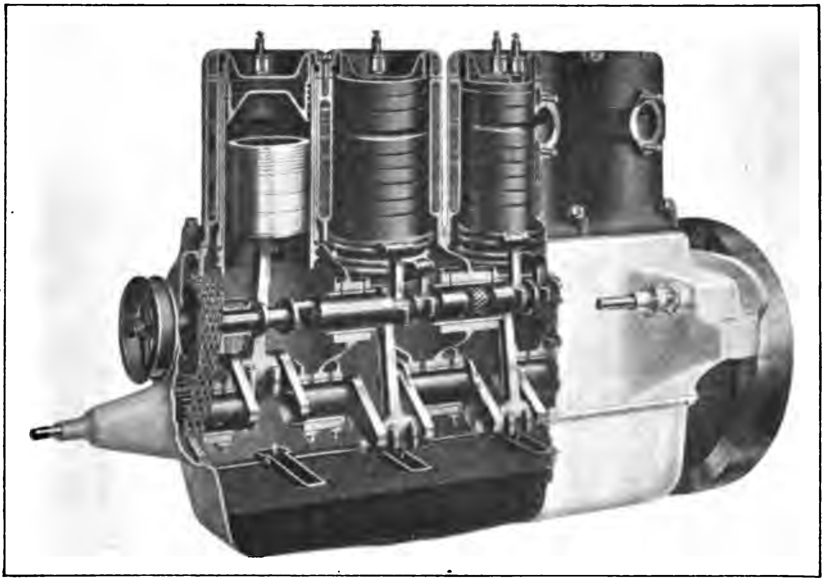


FIG. 71.—Columbia Knight Motor, Showing Sleeve-Valve Arrangement.

Knight Slide Valve Motor.

The impact of poppet valves on their seats, and the cams, springs, etc., which operate them, are a source of noise in an engine. This noise is eliminated in the Knight motor. The principal advantage claimed for this valve mechanism is that the inlet and exhaust passages are fully twice the size of the gas passage obtainable in a liberal design of the tee-head poppet valve motor, and nearly three times the size of the gas passages in the ell-head or valve-in-head motor.

Figs. 71, 72 and 73 show the general features of design as adpoted by the United Motor Company in the Columbia. The cylinder heads are removable. They are depressed, water-cooled and contain two spark plugs for Bosch or other double ignition. The valves for each cylinder consist of two sleeves made of very hard Swedish grey iron. Both inner and outer sleeves are open

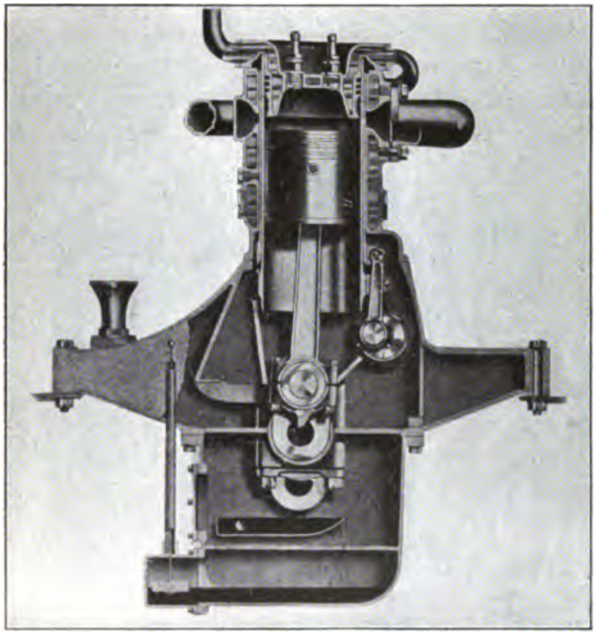


FIG. 72.—Columbia Knight Motor, Cross-Section View.

at both ends and each sleeve has openings on two sides. These sleeves are reciprocated to perform the valve function by short connecting rods actuated by a lay crankshaft at half speed by "Coventry" silent chain.

As seen from the cuts the outer sleeve, driven by a connecting rod from a countershaft on the right, Fig. 72, moves up and down between the cylinder wall and the inner sleeve. The inner sleeve,

driven by its connecting rod from the same countershaft, Fig. 71, moves up and down between the outer sleeve and the piston. The inner wall of this inner sleeve forms the combustion chamber wall.

The travel of the sleeves is only about one inch and the power required to overcome their friction and drive them is no greater than that necessary to actuate poppet valves for an engine of the same size. The eccentric driving the inner sleeve is given a certain advance or "lead" over that driving the outer one.

Operation.—During the suction stroke the right-hand slots of the inner and outer sleeves register, forming a large opening for the charge to enter. At the end of the suction stroke one

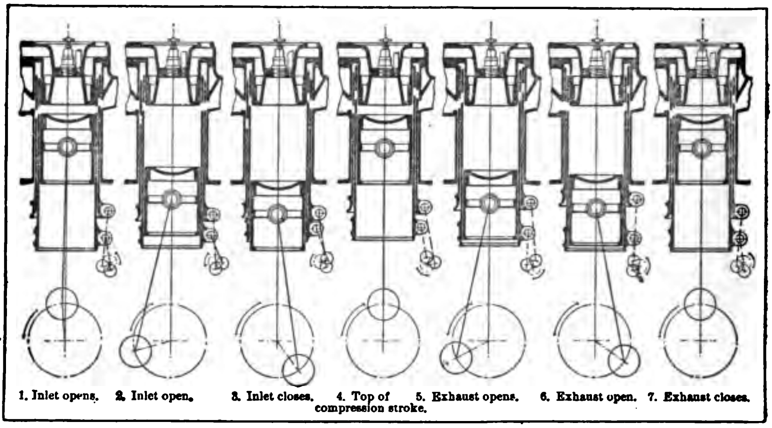


FIG. 73.—Relative Positions of Sleeves and Piston in the Operation of the Knight Engine.

sleeve moves up and the other down, closing the opening, and the compression stroke takes place. Compression being accomplished, the charge is fired in the usual way and the combustion or power stroke takes place, all slots still being out of register. At the end of the power stroke, movement of the sleeves brings the left-hand slots into register, and the opening thus formed is a large exhaust for the gases. This is best illustrated by Fig. 73, which shows seven points in one complete cycle.

The timing shown is not different from that ordinarily used in poppet valve engines. Timing of the valves is secured by varying the lead between the eccentrics that operate the two sleeves and by properly locating the slots in the sleeves. The amount of valve opening is practically unlimited and is governed by the width of the slot in the sleeves and the *throw* of the eccentrics that drive and determine the travel of the sleeves.

The Alcohol Engine.

The problem of alcohol vaporization was discussed under the chapter on carburetion. In appearance the engine is like an ordinary four cycle gasoline engine, but in design, since the useful effect of a given weight of denatured alcohol is 0.7 that of an equal weight of gasoline, the cylinder dimensions, inlet and exhaust passages, are increased in the ratio of 1.4 to 1 to get equal power. This increase and the modified carburetor are the only points wherein the alcohol engine differs from the gasoline engine. The compression is carried higher than in other liquid fuel engines. Recent experiments show that the alcohol engine can be started cold. The Deutz Company spray the alcohol into the admission line near the inlet valve. A mixture of equal weights of gasoline and alcohol gives an efficient performance in the gasoline engine without necessitating change of cylinder design.

CHAPTER XI.

AERIAL MOTORS.

The vast strides in aeronautical development due to demands of the present war, culminating in the enormous 900 H.P. Caproni triplane of Italy, capable of carrying three tons, and the attendant talk of the United States winning the war with a vast fleet of aeroplanes, makes this type of engine of particular interest at the time of writing. It is regretted that the scope of this book precludes a more comprehensive presentation of the subject. Aeroplane development is limited only by the degree of development of the gasoline engine.

The Essential Features for a successful aerial motor, in the order of their military importance, are (1) fuel and oil economy, (2) lightness, (3) reliability, (4) durability, (5) efficiency under varying operating conditions, (6) accessibility, and (7) simplicity.

(1) *Economy,* fuel and oil, is essential because the radius of flight is limited by the amount of fuel and lubricant the machine can carry. This is closely related to

(2) *Weight of Power Plant.*—A true comparison of aeroplane motors can be made only by considering the gross weight of the complete power plant, with fuel and oil, for the duration of a flight. In such a comparison the great advantage of fuel economy is evident; in a light but uneconomical motor it may even outweigh the advantage of light weight of motor. For example, the fuel and oil consumption of a well designed four-cycle motor is about .53 pound per H.P. hour, while the gross weight for a ten-hour flight is about 11½ pounds per H.P., whereas, the corresponding fuel and oil consumption and weight per horse-power of a light rotary motor are about .9 pound and 14 pounds. Obviously, if the requirements are a ten-hour flight,

the former engine is preferable. Light motor weight is a matter of design, materials and workmanship. Recently aluminum alloys of copper, zinc, tin, magnesium, nickel, tungsten, chromium and antimony have played a most important part in weight reduction. They are used successfully for crank cases, cylinders, pistons and for many minor castings.

(3) *Reliability* is more essential in the aerial motor than in any other type. The nature of the medium in which the machine operates and the fact that sustained flight is only possible when the motor is functioning properly makes this imperative.

(4) *Durability.*—Aerial motors have a shorter life than any other type gasoline engine because they are designed lighter per horse-power (about 1/3 the weight of the automobile engine), and, in service, their normal operation is at full power for long periods.

(5) *Efficiency* under varying load conditions is essential. Very little flying is done at ordinary levels, the very nature of the service required from a military machine involves sustained flights at high levels. As a machine ascends the air becomes rarified, the atmospheric pressure decreasing 3% to 4% per 1,000 feet above sea level. As a result the power developed by the engine decreases as the machine ascends. The reason for this is that, as the air pressure is reduced, the pressure at the end of the suction stroke is decreased, and, as a result, the pressure at the end of the compression stroke is less. Reducing the compression decreases the power.

(6) *Accessibility* of parts to facilitate adjustments and repairs is very desirable.

(7) *Simplicity* is essential because only by constant inspection and overhaul can successful operation be insured.

Characteristics.—All successful aeroplane motors are single acting, use gasoline for fuel, and nearly all are four-cycle. Both water and air cooled motors are in use, rotary motors always being air cooled. Radiators are similar to but lighter than those used in automobiles, and are specially designed to reduce head resistance. Engines for aerial work must be carefully balanced

to eliminate vibration. Small motors are started by hand from the operator's seat, but motors of 150 H.P. and over are generally fitted with an air actuated self-starter.

Types.—Aeroplane motors may be classed as follows: (1) Vertical, (2) Diagonal or "V" type, (3) Horizontal opposed, (4) Radial, and (5) Rotary.

1. Vertical Aeroplane Engines.

The vertical type of aeroplane engine is a development from the automobile engine. It is distinguished by its light weight, perfect balance, and other features of design adapted to its particular field. Thus, when the machine is upside down, there must be no danger of fire and the carburetor must function perfectly. Practically all vertical engines have two spark plugs per cylinder (two point ignition).

Military Motors. For military purposes the following Vertical motors are in most common use: American—Hall-Scott, Dusenberg and Union; English—Beardmore, Green and Rolls Royce; Italian—Fiat, Isotta Fraschini and S. P. A.; French—Renault; German—Mercedes, Benz and Maybach.

Hall-Scott Model A-5 Motor, Fig. 74.—This is a vertical, water-cooled six cylinder, four cycle engine of 125 H.P. at 1,300 revolutions per minute, with a 4-inch bore and 5-inch stroke. It weighs about 5 pounds per H.P.

Cylinders are cast separately of semi-steel (a special mixture of grey and Swedish iron) with integral cylinder heads, great care being exercised in casting and machining these to have the bore and walls concentric with each other. Small ribs are cast between the outer and inner walls to assist cooling and to transfer stresses direct from the explosion to holding-down bolts that run from the main bearing caps to the cylinder tops. Ample water jackets are provided around the head and valves, there being two inches of water space above the latter.

The cylinder is annealed, rough machined, then the inner cylinder wall and valve seats are hardened and ground to mirror finish to add to the durability of the cylinder and to diminish

friction. The cylinder sides are machined so that when assembled on the crank case the cylinders form a solid block.

Pistons are cast from the same semi-steel mixture as the cylinders; they are extremely light, and are provided with six deep ribs under the arch head. Pistons are first annealed, machined close to size, and then hardened and ground to a mirror finish.

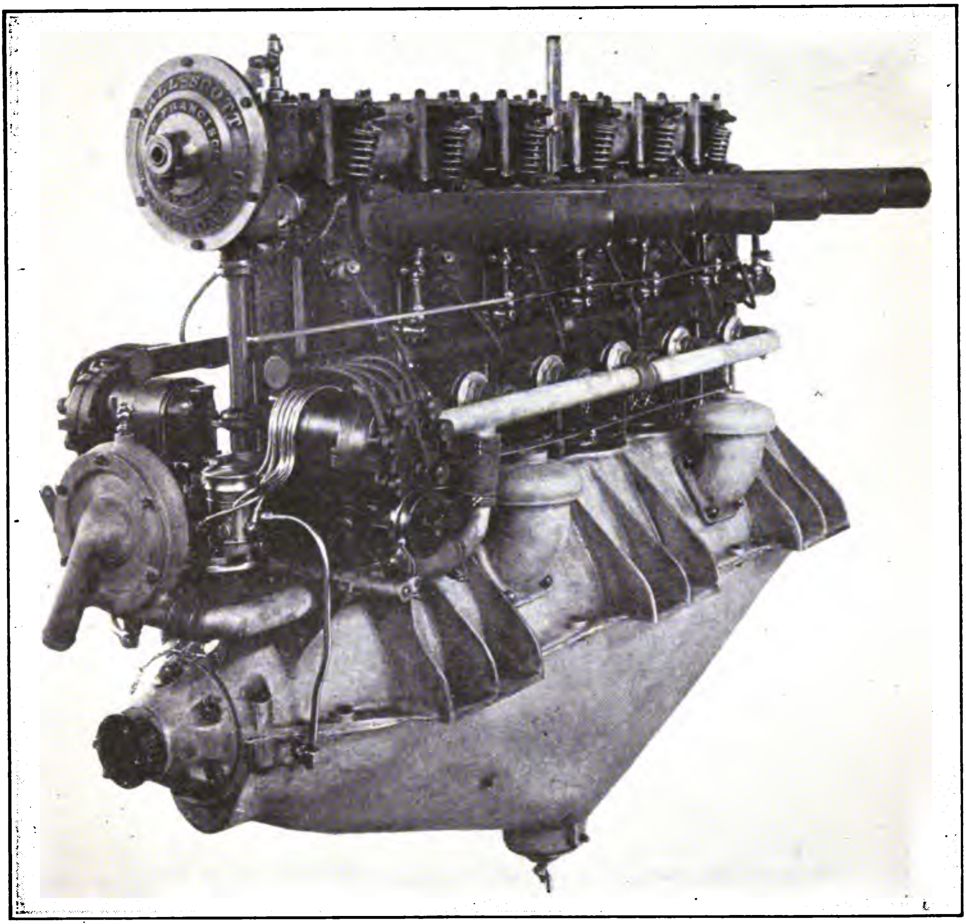


FIG. 74.—Hall-Scott, Model A-5, Aeroplane Motor.

The piston pin bosses are located very low so that the heat from the piston head is kept as far from the upper end of the connecting rod as possible. There are three ¼-inch piston rings.

Connecting Rods are of the I-beam type, milled from solid chrome nickel forgings, and are well balanced. The piston end is fitted with a gunmetal bushing. The crank pin end carries two bronze serrated shells, which are tinned and babbitted hot and broached to harden the babbitt.

The Crank Shaft is of the seven bearing type, being cut from a billet of chrome nickel steel of 275,000 pounds tensile strength. The bearing surfaces are extremely large, this being accomplished without undue length of motor by offsetting the webs of the shaft, a novel feature. This offset acts as an oil scooper for oiling the connecting rods. Two thrust bearings are installed on the propeller end of the shaft, one for pull and one for push. Timing gear and starting ratchets are bolted to a flange turned integral with the shaft.

The Cam Shaft is a one piece, low carbon chrome nickel steel forging, cams, air pump eccentrics, and gear flange being integral. It is enclosed in an aluminum housing bolted directly on top of all six cylinders, being driven by a vertical shaft in connection with bevel gears. This shaft, in conjunction with rocker arms, rollers and other working parts, are oiled by forcing the oil into the end of the shaft, using same as a distributor, allowing the surplus supply to flow back into the crank case through the hollow vertical tube. This supply oils the magneto and pump gears.

Valves.—Extremely large tungsten valves, one-half the cylinder diameter, are seated in the cylinder head and are operated by the overhead one-piece cam shaft in connection with short chrome nickel rocker arms. These arms have hardened tool steel rollers on the cam end, with hardened tool steel adjusting screws opposite. This construction allows accurate valve timing at all speeds with least possible weight.

Large diameter oil tempered springs held in tool steel cups locked with a key are provided. The ports are very large and short, being designed to allow the gases to enter and exhaust with the least possible resistance.

Gears.—All gears, with the exception of the two bronze oil pump gears, are of chrome nickel steel and where possible are bolted to flanges or made integral with the shaft, and are enclosed to run in oil.

Crank Case and Oil Sump are cast of aluminum alloy, hand scraped and sand blasted inside and out. The lower oil case can be removed without breaking any connections, giving access to the connecting rods and other working parts. The lower case holds eight gallons of oil.

Carburetion.—A double Zenith carburetor, having one float chamber, is provided. Automatic valves and springs are absent, making the adjustment simple and efficient. This carburetor is not affected by altitude. It is bolted directly to the engine base from which it receives its warm air. This also tends to keep the crank case cool. A Hall-Scott device, covered by U. S. patent, circulates the oil from the crank case around the carburetor manifold, thus assisting carburetion as well as reducing crank case temperature.

Ignition.—Two six cylinder Bosch magnetos furnish current, there being a set of spark plugs for each magneto. Both magneto interrupters are connected to a rock shaft integral with the motor, making outside connections unnecessary.

It is worthy of note that with this independent double-magneto system one complete magneto can become indisposed and still the motor will run and continue to give more than three-quarter power.

Lubrication is by the high pressure system, oil being forced to the under side of the main bearings at a pressure of five to thirty pounds. This system is not affected by the extreme angles obtained in flying. A large geared pump runs submerged in the lowest point of the oil sump, thus doing away with troublesome stuffing boxes and check valves.

Oil is first drawn from the strainer in the oil sump to the long jacket around the intake manifold, then it is forced to the main distributor pipe in the crank case which leads to all main bearings. A by-pass located at one end of the distributor pipe regulates the oil pressure, the surplus oil being returned to the case.

Independent of this system, a small six-plunger pump feeds oil to each individual cylinder. The stroke of the plungers can be separately adjusted to regulate this supply. A strainer and a dirt, water and sediment trap are located at the bottom and center

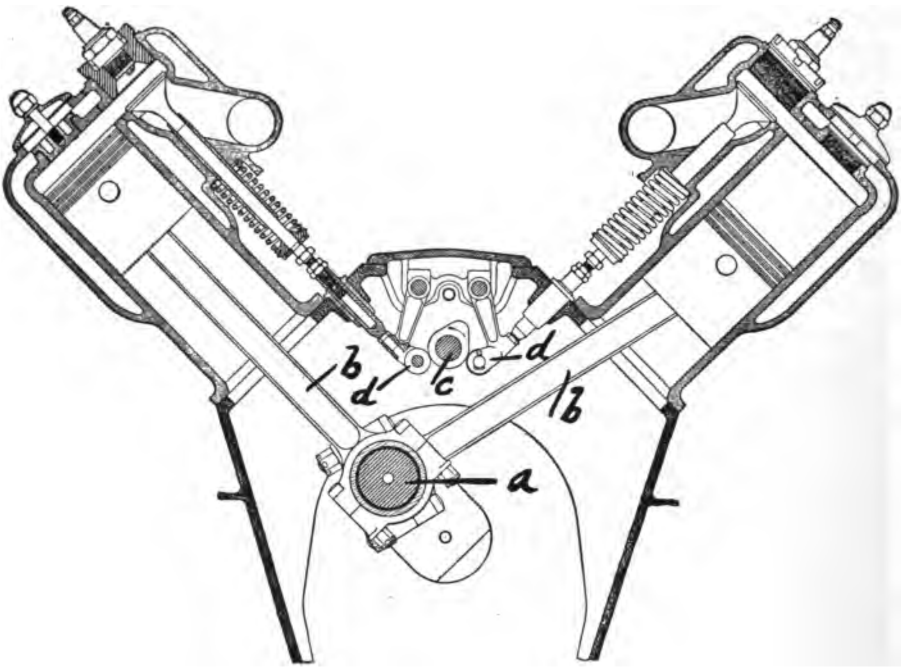


FIG. 75.—Cross Section of V-Type Motor.

of the oil sump. This can be removed without disturbing the oil pump or any oil pipes. A small oil pressure gage on the instrument board registers the oil pressure.

Cooling System.—Cooling this motor is accomplished by oil as well as by water, by circulating the lubricating oil around a long intake jacket. The carburetion of gasoline cools this oil and the crank case heat is therefore kept at a minimum regardless of weather conditions.

The water is circulated by a large centrifugal pump that pro-

vides ample circulation at all speeds; water enters at the bottom of the water jackets. An ingenious internal outlet pipe runs through all six cylinders, the joints being made with packing nuts. Slots are cut in this pipe in each water jacket so that the circulating water is drawn directly around the exhaust valves. This maintains a uniform cylinder temperature.

A Starting Crank is mounted in a compact aluminum housing securely bolted to the main crank case, thus forming an integral part of the motor.

2. V Type Engines.

It is obvious that, as the number of cylinders of a vertical motor is increased, the crank shaft and crank case become very heavy and finally the number of cylinders reach a limit; modern designers place this at eight. The V type motor is designed to reduce the weight for a given number of cylinders by arranging them at an angle in pairs, the case and shaft being common to both cylinders of a pair.

Thus an eight cylinder V type motor has its cylinders arranged in two sets of four cylinders each, the sets being opposite one another at an angle, generally 90°, the connecting rods of corresponding cylinders of the two sets working on the same crank, Fig. 75. An eight cylinder motor crank shaft has four cranks, each crank *a* operating two connecting rods, *b, b*. The cam shaft *c* is driven through gearing or by chain drive from the main shaft *a*. Each cam operates two push rods, *d, d*.

This design is being widely adopted both here and abroad for engines of eight and more cylinders. It cannot be so perfectly balanced as the radial or rotary engine, but to offset this its head resistance is less than either of those types. Nearly all V type motors are water cooled. Eight cylinder motors are generally provided with two magnetos, one for each bank of four cylinders, and twelve cylinder motors generally have three, one for each bank of four cylinders.

Military Motors. For military purposes the following V-type motors are in most common use: American—Liberty, Sturtevant, Curtis and Thomas; English—Rolls Royce, Sunbeam and Hispano Suiza; Italian—Fiat and S. P. A.: French—Renault, Hispano Suiza and Lorraine.

Sturtevant Model 5 A Motor, Fig. 76.—This is a V-type, water cooled, eight cylinder, four cycle engine of 140 H.P. at 2,000 revolutions per minute, with a 4-inch bore and 5-inch stroke. It weighs 4 pounds per H.P.

Cylinders are cast of an aluminum alloy in pairs and are fitted with steel liners. A molded copper asbestos gasket is placed between the cylinder and head insuring a tight joint. The cylinder heads are cast in pairs of aluminum alloy with ample water passages. Each cylinder is held to the base by six long bolts which also pass through the heads.

Pistons, which are made very light from a special aluminum alloy to reduce vibration and wear of bearings, are deeply ribbed in the head for cooling and strength, and are provided with two piston rings. The wrist pin is made of chrome-nickel steel, hollow bored and hardened; it turns in both piston and connecting rod.

Connecting Rods are made in H-section of air hardening chrome nickel steel, having a tensile strength of 280,000 pounds per square inch. The crank ends are lined with white metal and the wrist pin ends are bushed with phosphor bronze.

Crank Shaft.—This is machined from heat treated chrome nickel steel. It is 2¼ inches in diameter and bored hollow throughout to obtain maximum strength with minimum weight. It is carried in three large, bronze backed white metal bearings.

The Cam Shaft, which is supported by six bronze bearings in the upper half of the crank case between the two banks of cylinders, is hollow bored throughout and the cams are formed integral with the shaft.

The Gears that operate the cam shaft, magneto, oil and water pumps are contained in an oil tight casing and operate in an oil bath.

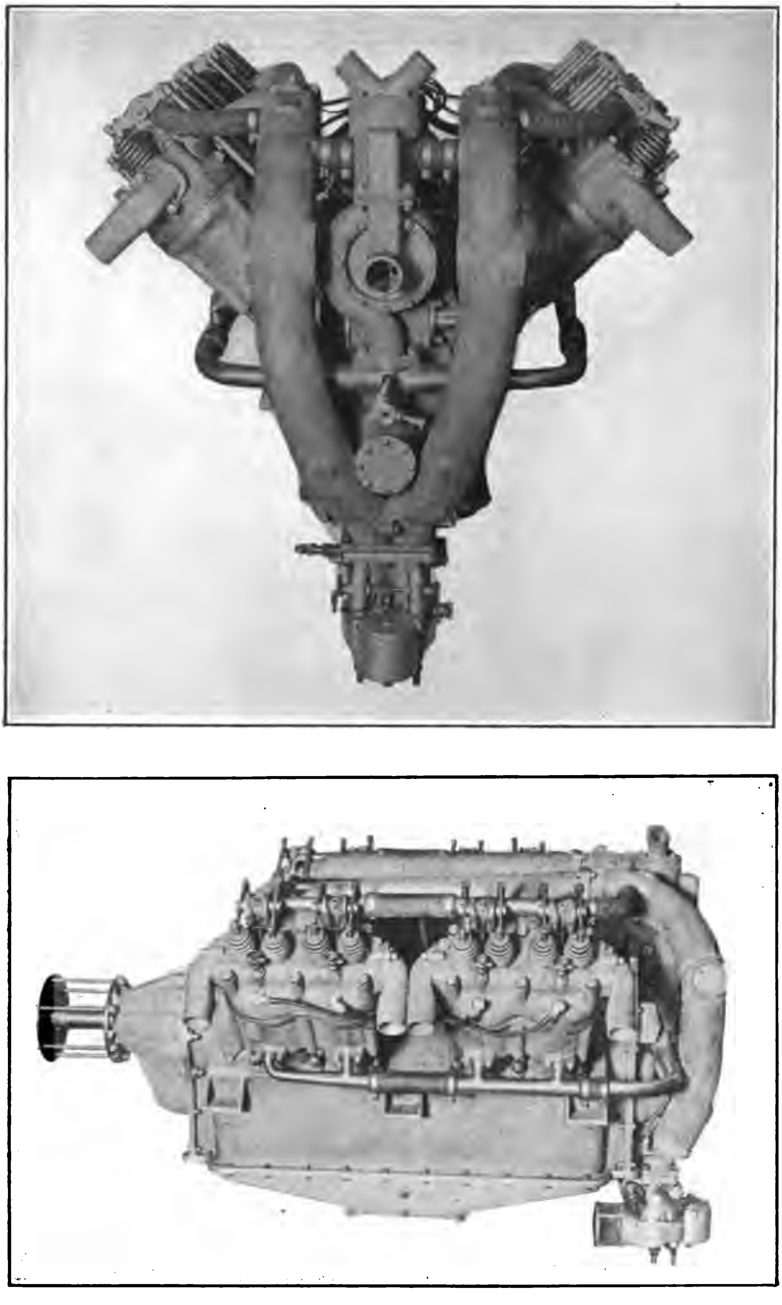


FIG. 76.—Side and End View Sturtevant Aeroplane Engine.

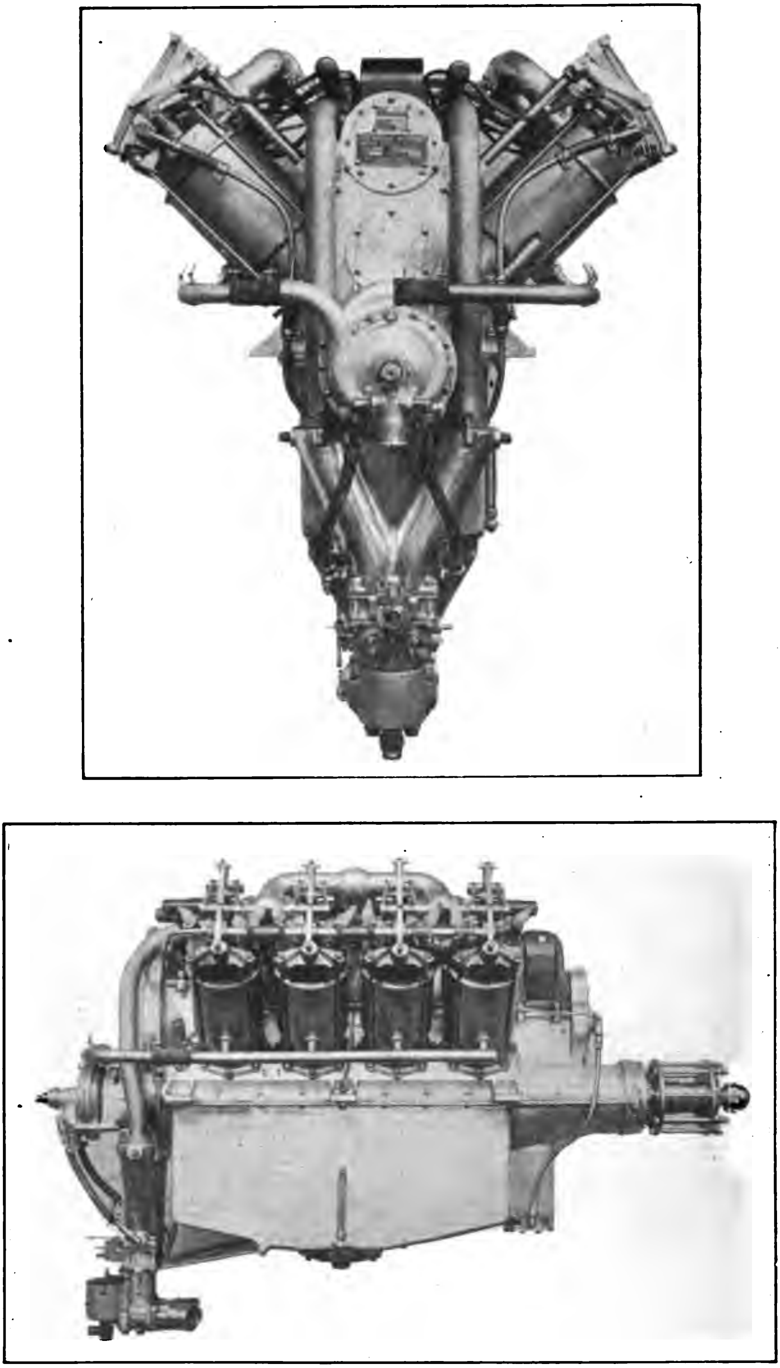


FIG. 77.—Side and End View Curtiss OXX3 Aeroplane Engine.

Valves are of hardened tungsten steel, mechanically operated, and are of generous proportion. They are operated by rocker arms, one for each valve, off the cam shaft. A system of double springs reduces the stress on each spring; a large diameter spring returns the valve, while a second spring at the cylinder base handles the push rod linkage.

The Crank Case is cast from an aluminum alloy deeply ribbed at points of high stress. The lower half contains the oil sump, which is entirely covered by an oil filtering screen.

Carburetion.—The carburetor is the Zenith duplex type. It is a double barrel design with one float chamber and two jets, each jet supplying one bank of four cylinders. It is located at the rear end of the motor beneath the level of the engine base, thus permitting of gravity feed. It is connected to the cylinders by means of aluminum manifolds, having integral cast water jackets.

Ignition is by two eight cylinder waterproof Bosch or Splitdorf magnetos placed face to face between the two banks of cylinders. Each cylinder is provided with double ignition by means of two spark plugs located in water cooled bosses on the sides of the cylinder heads.

Lubrication is of the complete forced circulation system, oil being supplied to every bearing by a large capacity rotary pump, which is gear driven from the cam shaft.

Starting Crank.—The engine can be started from the machine by a crank handle or an air starter can be readily installed.

3. Horizontal Opposed Engines.

Military Motors. The Horizontal Opposed motor has not found any extended use in the military field.

The Ashmusen Motor, Fig. 78, is of the horizontal opposed-cylinder type; it is a four-cycle, air cooled, twelve cylinder engine, having a bore of 3¾ inches, stroke of 4½ inches, and develops 105 H.P. at 1,800 revolutions per minute. It weighs about 360 pounds.

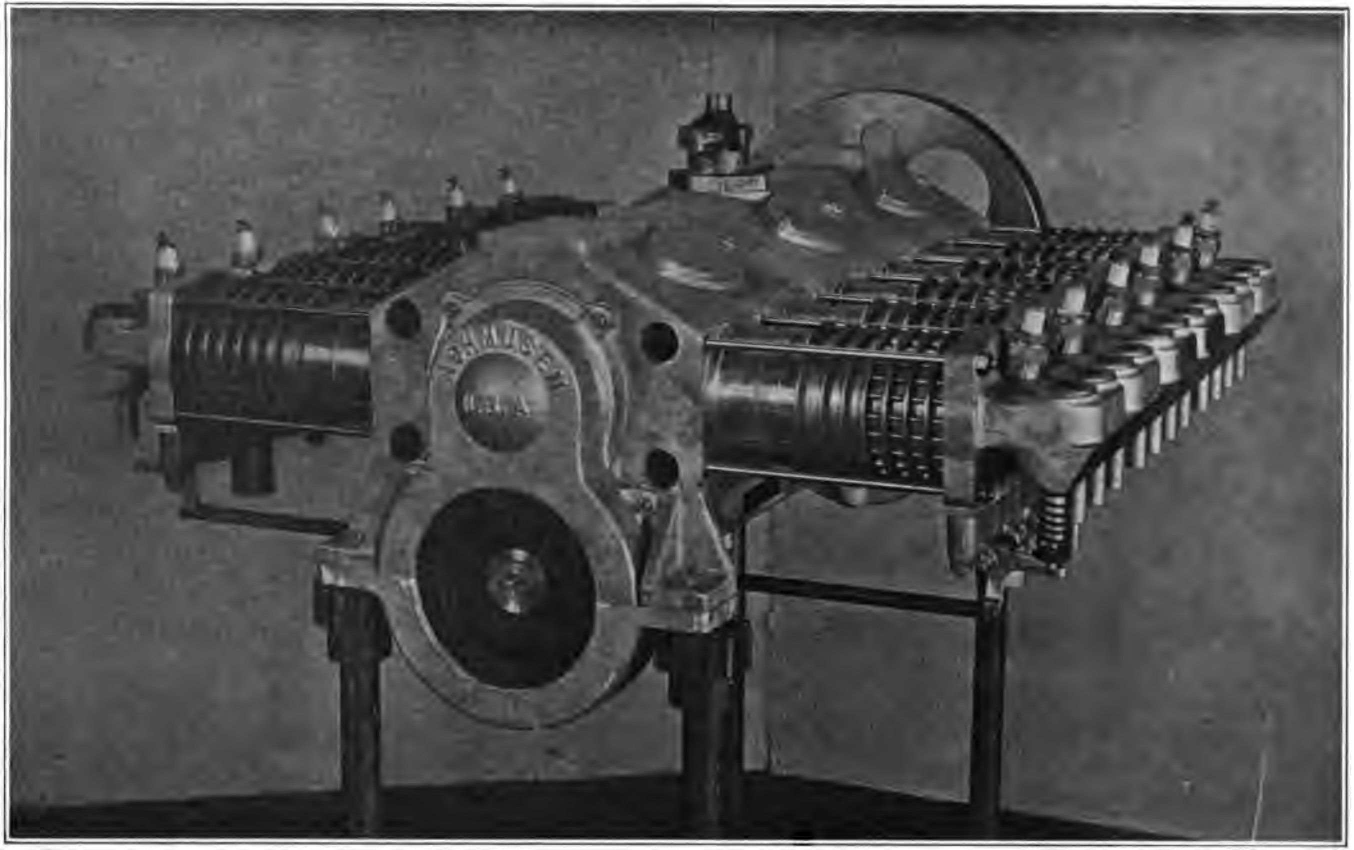


Fig. 78.—Ashmusen, 105 H.P., Aeroplane Motor.

It is equipped with two improved Ashmusen carburetors and double manifolds. Air is drawn through flutes on the sides of the cylinders to the manifolds, thence to the carburetors. This system accomplishes the double purpose of cooling the cylinders and heating the air to the carburetor. Delco ignition is used. The propeller is driven from the cam shaft at one-half motor speed. The cylinders, cylinder heads and pistons are of grey iron. The crank shaft is a heat treated nickel steel forging. The crank case is aluminum alloy. The valves are tungsten steel. Main and cam shaft bearings are of the ball type. Wrist pin bearings are of Parson's metal. A compression release is fitted

FIG. 79.—Anzani Motor with Muffler.

to hold the exhaust valves off their seats. Perfect balance, minimum vibration, and accessibility are claimed, the makers stating that it is possible to remove all cylinders and replace them in 45 minutes.

4. Radial Aeroplane Engines.

Radial motors are designed with the cylinders disposed radially about the center line of the shaft, Fig. 79. Valves are located in

the cylinder head. Radial motors are air cooled and water cooled. The radial motor can be more perfectly balanced than can other types, but this advantage is offset by the higher head resistance offered by the motor.

Military Motors. For military purposes the following Radial Motors are in most common use: French-Salmson; English-A. B. C.

The Anzani Motor is an air cooled motor built in banks of three or five cylinders, being rated at about 10 H.P. per cylinder at about 1,200 revolutions. Fig. 79 illustrates the 100 H.P. Anzani Motor. It is built in two banks of five cylinders each. Fig. 80 is a cross section of the 60 H.P. six cylinder motor, with one bank of cylinders removed.

The Crank Case M M is aluminum alloy, made in halves, connected together by through bolts *N N*. These bolts also serve to attach the engine to the aeroplane. A dirt and sediment sump is fitted in the bottom of the case.

Cylinders K K are of cast iron, with cooling ribs, the flat cylinder tops containing the inlet and exhaust valve seats. The cylinders are slightly offset. They are attached to the crank case each by two long bolts connected to the through crank case bolts *N* at the inner end and passing through bosses on the cylinders at the outer end, as shown at *L*. These through bolts take the longitudinal strains due to the explosions.

Pistons H are of cast iron, ground to fit and provided with stiffening ribs on the under side of the flat crown. There are two piston rings. The wrist pins are hollow, of nickel steel, hardened and ground, and secured in the piston bosses by a set screw as shown.

Connecting Rods B are of high tensile nickel steel of H section with a plain bronze bushed wrist pin end. The crank pin end connection is shown in section in Fig. 80. Each connecting rod ends in a shoe *C*. The three shoes of each bank of cylinders bear on a cylindrical bronze sleeve *D* (made in halves), which embraces the crank pin and rotates thereon; the whole is held together by two bronze collars *E E*.

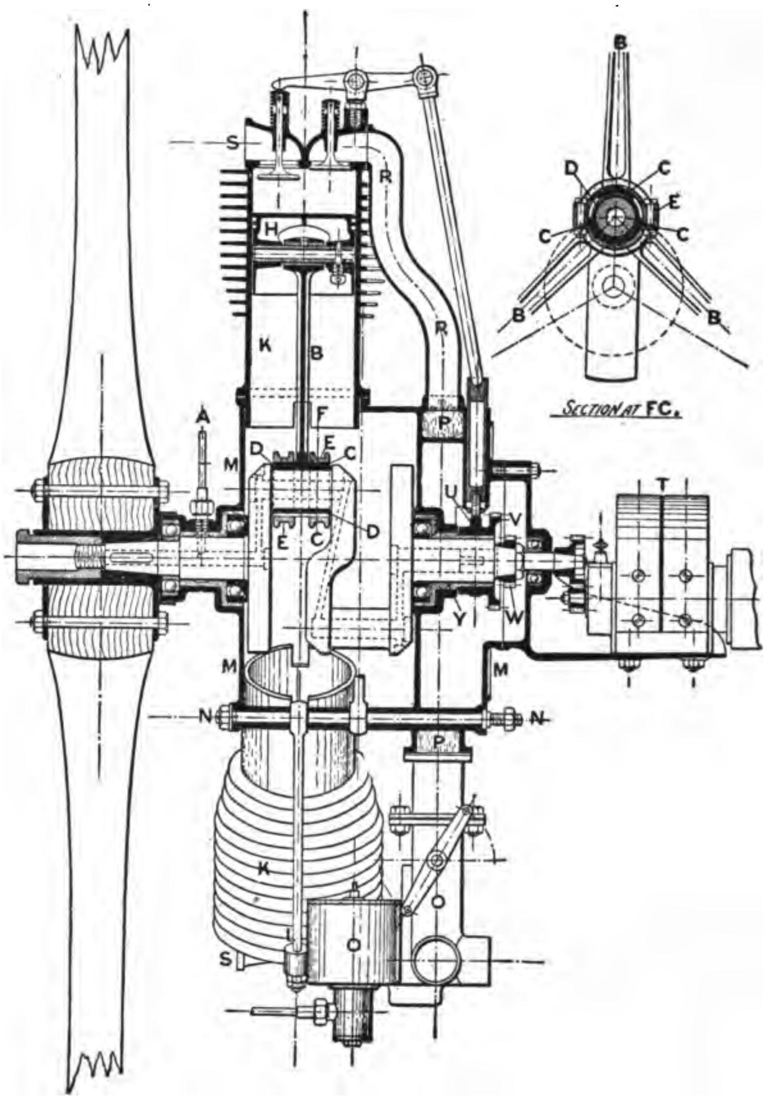


FIG. 80.—Cross Section of Anzani Motor.

Valves are of nickel steel and of large diameter. The inlet valves are spring loaded automatic valves, a bad feature that will probably be abandoned. The exhaust valves are operated through push rods and rocker arms by the cam *U*. This cam is made integral with its driving pinion *V* which runs on the bronze sleeve *Y;* it is driven from the pinion *W* through intermediate gears.

Carburetion.—A Zenith carburetor is used. From the carburetor the mixtures goes to the annular chamber *P* surrounding the rear end of the crank case, and from this chamber pipes *R* lead to the inlet valves. The exhaust can be discharged directly to the atmosphere at *S* or a collector muffler can be fitted, Fig. 79.

Ignition is by high tension magneto *T,* gear driven from the rear end of the crank shaft. Two spark plugs are fitted to each cylinder.

Lubrication.—A cam operated plunger type oil pump (not shown) is formed on the crank case cover. It delivers oil at *A* under pressure, and oil is supplied to the pistons, wrist pins, and

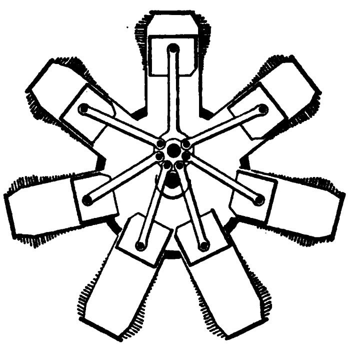


Fig. 81.

all internal parts through the crank shaft. An oil fog is maintained in the crank case when the engine is running.

5. Rotary Aeroplane Motors.

The distinguishing feature of a rotary motor is that the crank shaft and crank are stationary and the cylinders revolve about the shaft. This produces the same relative motion of pistons to

cylinders as though the cylinders were stationary and the crank revolved. From Fig. 81, showing the connections between the pistons and the crank shaft in a rotary engine, it is obvious that it matters not which is the revolving member. The relative piston-cylinder positions will be the same.

The rotary motor has several inherent disadvantages. The head resistance is greater than in a stationary motor. It is estimated that 7% to 9% of the power developed is expended in overcoming the effect of the whirling cylinders. Power is consumed in driving the cylinders about the shaft. The gyroscopic effect of the whirling cylinders is a handicap to the operator. The lubricating waste is large, the compression is low, and the engine cannot be satisfactorily muffled.

The crank shaft is secured to the aeroplane. The propeller is made fast to the front of the cylinder base and revolves with it.

Military Motors. The Gnome motor is the most widely used of the rotary motors in military aeroplanes; it is shown in cross section in Fig. 82.

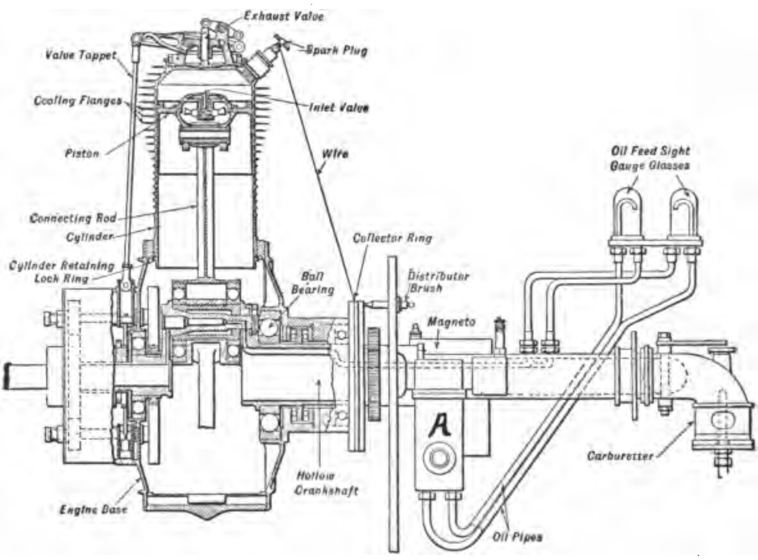


FIG. 82.—Cross Section of Gnome Motor.

Gnome Engine.—*The cylinders* are made of forged chrome nickel steel, about 1/16 inch thick with cooling fins on the outside. They are secured to the crank case by a lock ring.

The crank case is of nickel steel in the form of a hoop having holes bored in the circumference to seat the cylinders.

The carburetor is in the rear of the engine, the charge passing through the hollow shaft to the crank case.

Automatic inlet valves in the piston heads admit the charge to the cylinders.

Exhaust valves in the cylinder heads are operated by an arrangement of female cam plates bolted to the cylinder base and male cam plates on the crank shaft. Motion is transmitted to the valves by push rods.

Ignition is by high tension magneto direct to spark plugs, via a very simple distributor; the spark is advanced automatically.

Lubrication is by forced feed. The oil pump *A,* Fig. 82, forces oil through the oil sight feed gage glasses and pipes in the hollow crank shaft to the bearings and by ducts to all points requiring lubrication.

The Gyro Duplex Motor, Fig. 83.—This is an American-built 9 cylinder, air-cooled rotary motor, developing 100 H.P. (normal) at 1,130 R.P.M.; bore, 4½ inches; stroke, 6 inches; weight, 270 pounds.

Cylinders are turned from solid billets of special alloy steel, with cooling fins on the outside, and carefully balanced to eliminate vibration.

Pistons are of the best grade cast iron, fitted with oil deflectors for economy, and two piston rings of special design.

Connecting rods are of vanadium steel and heat treated. The connecting rod assembly, or *spider,* is carefully balanced.

Crank shaft is of nickel steel, drilled out for lightness, and serves as a gas and oil passage to the crank case.

Crank case is of vanadium steel, made in two halves, the cylinders being clamped between the two halves.

Cam valve drive is of the Duplex type driven from a differential gear train.

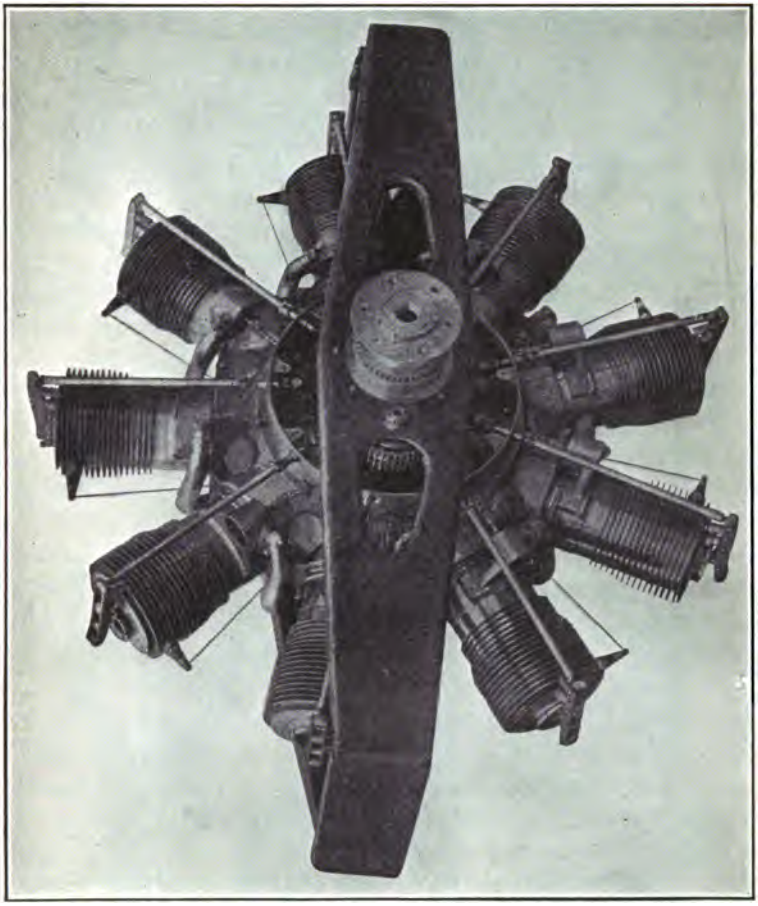


Fig. 83.—Gyro "Duplex" Aeroplane Motor.

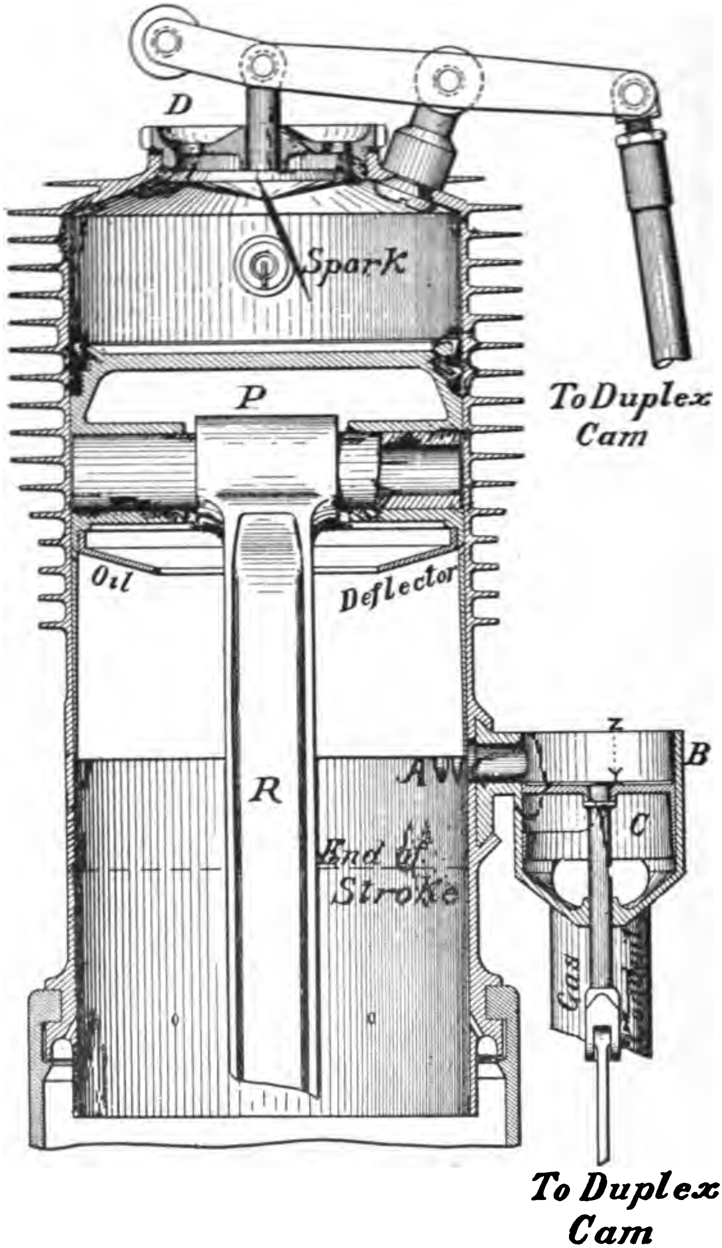


FIG. 84.—Section Through Cylinder—Gyro "Duplex" Aeroplane Motor.

Ignition is by Bosch high tension magneto direct to spark plug, via a simple distributor.

Carburetion is semi-automatic, gasoline being fed to the crank case through a gear driven pump and a spray nozzle.

Lubrication is automatic and absolutely positive, being supplied by a gear driven displacement pump to the central bearing and from there through ducts to all points of friction.

A variable compression cam allows the motor to start readily and to run idle at 250 to 300 R.P.M. There are no inlet valves, back pressure is reduced, back-firing eliminated, and no oil waste occurs through the piston head.

Operation, Fig. 84.—The inside of the motor is bare of all accessories save the piston *P,* the connecting rods *R,* and the crank shaft. The main exhaust valve *D* is located on the cylinder top and is operated by a rod and cam. This cam is of the ***duplex*** type, one side operating the main exhaust, the other the slide intake mechanism *B, C;* the latter is attached to the outside of the cylinder about two inches above the end of the power stroke. It is readily detachable.

At this point there are provided auxiliary exhaust ports *A,* through which the main pressure of the nearly-spent stroke exhausts itself, thereby reducing the pressure necessary to open the main exhaust valve. Outside of these ports is a cage, *B,* in which a small hollow slide, *C,* moves with a stroke of about one-half inch, *y* to *z;* this stroke depends upon the shape of another cam forming a twin to the main exhaust cam.

The operation is as follows: When the power stroke reaches the auxiliary ports *A* the gases escape and relieve the pressure in the cylinder. The piston continues 1½ inches, to the end of the stroke, and then returns for scavenging the burnt gases out through the main exhaust *D;* the piston then moves down for the intake.

The exhaust *D* remains open until just before the piston on its intake stroke reaches the auxiliary ports *A.* In the meantime the small intake slide *C* has moved outward to *z* and the auxiliary port *A* is now connected through the cage *B* to a gas conduit filled with fresh mixture. The main exhaust has closed and the piston moves 1½ inches farther and sucks the fuel into the cylinder. The intake slide *C* then returns to its original position, while the piston moves outward on the compression stroke.

CHAPTER XII.

THE DIESEL ENGINE.

This engine, the invention of the late Mr. Rudolph Diesel, of Munich, differs in its cycle from all previous internal combustion engines in compressing a *full charge of air* to a temperature above the ignition temperature of the fuel, then injecting the fuel for a certain period (variable according to the load) into this highly heated air where it burns with limits of temperature and pressure under perfect control. *No fuel is present in the cylinder during compression* (this is the distinctive Diesel feature), and a uniform combustion takes place at a predetermined temperature, the combustion line being represented as an isothermal.

Classification.—Diesel engines are broadly classified as two cycle and four cycle. In both types a cylinder full of air at about atmospheric pressure is compressed by the piston until at the top center its pressure becomes about 500 pounds per square inch, and its consequent temperature about 1,000° F. At this instant a small quantity of oil fuel is blown into the very hot compressed air by means of a jet of air at a still higher pressure.

Operation.—The fuel valve is so designed that the oil is broken into a fine spray and *admission* lasts only about one-tenth of the downward stroke. During this short time much of the oil is burned in the hot air. The heat generated by the combustion raises the temperature greatly, and consequently must increase either or both the pressure and the volume occupied. As a matter of fact, the aim is to have combustion proceed at the critical rate which would permit the increase of volume occupied, due to the motion of the piston and the increased temperature, to be so balanced that the pressure will remain constant throughout combustion.

After combustion is complete, expansion of the hot gas will still further push the piston down, and the pressure will decrease

rapidly. The temperature will also fall rapidly, mainly from conversion of part of the heat into work, but also partly by the radiation of some of the heat through the cylinder walls to the surrounding cooling water.

The Maximum Temperatures actually attained in the cylinder are very high, approximating in some cases to nearly 3,000° F. It is these excessively high temperatures that occasion some of the Diesel engine difficulties. It is necessary to keep the rubbing surfaces of the metal which are exposed to the hot gases sufficiently cool to permit them to retain their lubrication, and it is also necessary to prevent all metal which comes into contact with the heat from becoming so overheated as to damage its strain-resisting properties.

These extremely high temperatures also complicate the questions of expansion of the cylinder materials and hence the foundry work involved. The consequent high pressures cause unusually high tension stresses in the columns, tie rods, cylinders, etc., and make for heavy vibrations.

Design Problems.—The above engineering problems were new to prime movers and had to be solved before a *successful* Diesel engine could be produced. Adequate cooling systems have been devised to handle the high temperatures, heavy columns and tie rods to meet the high tension stresses have overcome the vibration. The expansion problems had been solved, to a limited extent, in the foundries.

While it may be admitted that the early claims were much too sanguine, and that the glowing anticipations of the early enthusiasts have not as yet been entirely fulfilled, yet there is no doubt that the development of this engine thus far justifies a wonderful outlook for its future.

The Reasons for the Success of certain designs are worthy of study as marking the trail of future progress. Over-ambition led to excessive increase in sizes of the units without first overcoming the difficulties involved. Also, attempts were made to convert the land engine to marine use without first adapting it to this new work. In the successful engines increase of power has

generally been attained by multiplying the units instead of indefinitely increasing the size of the unit; price has not been cut; weight has not been sacrificed; simplicity has not been forced.

The Well Known Advantages of the oil engine for naval use, namely, the saving in space, weight, fuel and personnel, and the possibility of getting underway quickly, has repeatedly caused predictions that the oil engine must be developed for larger powers. The largest American built marine Diesel installation is the 5,000 H.P. plant on the Naval collier *Maumee.*

Cycles.—The foregoing remarks apply to all types of Diesel engines. In the four-stroke cycle engine the exhaust takes place through valves in the cylinder covers, the gases being pushed out by the piston on its return stroke. During the next stroke fresh air is drawn into the cylinder through other valves also situated in the cylinder cover. It is compressed during the third stroke, and the fuel is then admitted in the same manner at the commencement of the next stroke, as in the two-stroke cycle type.

In the case of the two-stroke cycle engine, just before the completion of the expansion stroke the piston uncovers ports in the lower part of the cylinder walls leading into an exhaust passage, and a considerable portion of the hot gas escapes, the pressure falling to about that of the atmosphere. Then in some designs valves in the cylinder cover are opened and fresh air supplied by the scavenger pump at a pressure of about 4 pounds per square inch blows out the remainder of the burnt gas, leaving the cylinder full of fresh air ready to be compressed by the return stroke of the piston; in other designs the exhaust ports are placed on one side only of the lower end of the cylinder, and on the other side similar ports, also opened by the travel of the piston, but at a somewhat later instant, admit the scavenging air. In these latter cases the tops of the pistons are curved to direct the entering air upwards, and it is claimed that the scavenging air travels right to the top of the cylinder and entirely displaces the burnt gas. In these latter designs the scavenger valves and the gear for working them are dispensed with, and consequently the engines are to some extent simplified.

It will be observed that in the two cycle engine there is one impulse in each cylinder every revolution, while in the four cycle there is only one impulse per two revolutions, so that with the same diameter of cylinder and the same piston speed double the number of cylinders have to be used with a four cycle compared with a two cycle engine of the same power, if the same mean pressures are maintained. In both types a considerable part of the energy exerted during the impulse stroke is used up in the following compression stroke. Also in the two cycle large scavenger air pumps have to be provided, having an aggregate capacity greater than that of the whole of the cylinders, and considerable power is expended in working these pumps, and this must be taken off the effective power of the engine. On the other hand, the four cycle engine has the engine friction (pistons, guides, shafts, etc.) during twice the number of strokes as compared with the two cycle, and it also has to be provided with exhaust valves and gear to work them, which are not required in two cycle engines. On the whole there is no doubt that while the indicated power obtained from a stated quantity of oil is about the same in both types of engines working under similar conditions of compression and fuel supply, the four cycle engine is somewhat more efficient than the other, in that a larger proportion of the power exerted on the pistons is transmitted to the screw, owing to the fact that no power is expended in supplying scavenging air.

The Four Cycle Diesel.

This type, commonly called the American Diesel Engine, received most of its early development in this country. It is a vertical, four cycle, single acting, stationary engine, Fig. 85.

Fuel is pumped to the fuel chamber by a fuel pump. A two stage compressor, generally driven from the main shaft, serves to compress air to about 800 pounds pressure. This air is cooled before use, and is used only to inject fuel from the fuel chamber to the cylinder, and to charge an air tank for starting the engine when cold. An extremely sensitive governor controls the quan-

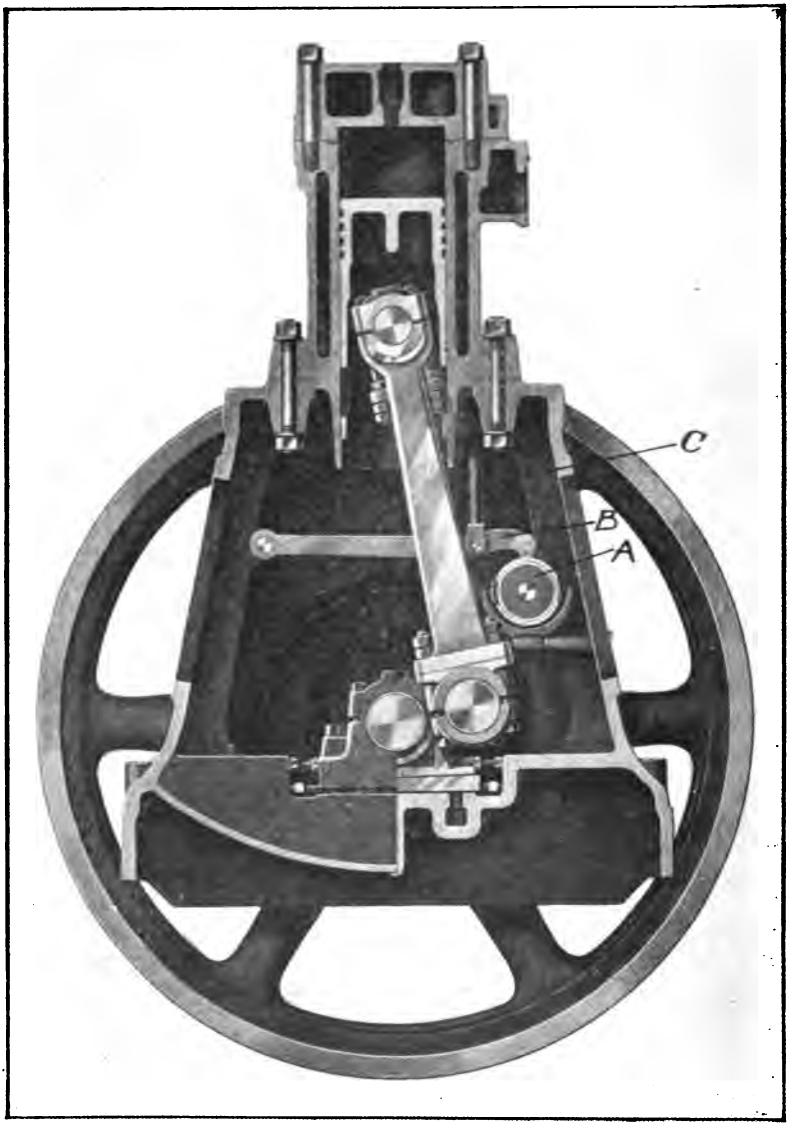


Fig. 85.—Diesel Engine, Four Cycle.

tity of fuel injected each stroke. So fine is this regulation that the engine can operate alternating current generators in parallel without difficulty.

The fuel used at half load rarely exceeds 55% of that used at full load, so the fuel consumption is nearly proportional to the work done. This very marked contrast to the performance of other types of engines is the result of features inherent in the Diesel cycle alone, and is due to direct regulation of the fuel supply by the governor.

CYCLE OF OPERATIONS.

As stated above, the fuel is not compressed, only air being in the cylinder during this stage of the cycle, hence pre-ignition is impossible. The clearance is very small. The complete cycle is as follows:

1. **Aspiration Stroke.**—The piston moves to the bottom of the cylinder and during this stroke the air admission valve opens and allows the cylinder to fill with air at atmospheric pressure.

2. **Compression Stroke.**—The piston moves to the upper end of the cylinder, the admission valve closes, and the air in the cylinder is compressed to 500 pounds per square inch, at which pressure its temperature is sufficient to ignite any form of petroleum (crude or refined) spontaneously. No valves are open during this stroke and there is nothing in the cylinder but pure air.

3. **Expansion Stroke.**—When the piston has reached the top of the compression stroke and the crank is just crossing the dead center, a small needle valve, Fig. 86, opens and a charge of liquid fuel mixed with compressed air is blown into the highly heated air already in the cylinder. Ignition take place as the fuel comes in contact with this hot air. The fuel valve, together with the air and exhaust valves, is placed at the side of the cylinder at the top end, and all valves open into the same space. The quantity of fuel is not all blown in at once; instead, fuel injection is maintained for a period equal to 10% of the downward stroke of the piston. It would be impossible to maintain this long period of admission if fuel alone were injected, but the compressed air,

which is blown in with the fuel and which is thoroughly mixed with the fuel by the perforated washers that surround the needle valve, increases the volume and thus gives a quantity whose injection can be controlled. The compressed air referred to is that supplied by the two stage compressor at 800 pounds pressure and cooled before introduction into the fuel valve.

After the needle valve closes, the hot gases expand until the piston has traveled 90% of its stroke, when the exhaust opens to relieve the pressure. The pressure at opening of the exhaust valve for normal load is generally 35 pounds per square inch, and the temperature about 700° F. The pressure in the cylinder is not due to the expansion of gases of combustion alone, for there is a large excess of air present and the high heat attained is sufficient to expand this excess air also.

4. Exhaust Stroke.—This fourth and last stroke of the cycle takes place on the upward stroke. The exhaust valve is open and the hot gases are forced out by the piston. When the piston reaches the top center, the exhaust valve closes, the admission valve begins to open and the cycle is repeated.

The engine is water cooled and the fuel and exhaust valves are operated as shown in Fig. 85. *A* is a cam on the countershaft, *B* is the cross rod with a roller bearing on the cam *A*, and *C* is the push rod that actuates the valve stem. Splash lubrication is used for the cylinder, and the main bearings are lubricated by an oil ring and an oil chamber. The fuel valve is made of nickel steel to prevent abrasion by the petroleum. The piston is of the long trunk type, being approximately 2 1/3 times the diameter in length, tapering 1/32 inch, and provided with four snap rings.

Governor.—The governor is connected to a by-pass at the fuel pump. The pump runs at constant speed. If the load is light and the fuel requirement is low, the governor holds the by-pass valve open and allows a large amount of oil to return to the suction side of the pump; when the load increases, more oil is required; the governor holds the by-pass open for a shorter period, less oil goes back to the pump suction and more goes to the engine.

Valve Group.—The group consists of the air and exhaust valves, which require no special consideration, and the fuel valve. This last consists of a needle valve *A* (Fig. 86), which is cam actuated from the cam *A* (Fig. 85) through the bell crank lever *D* (Fig. 86), always opening during the same period each cycle.

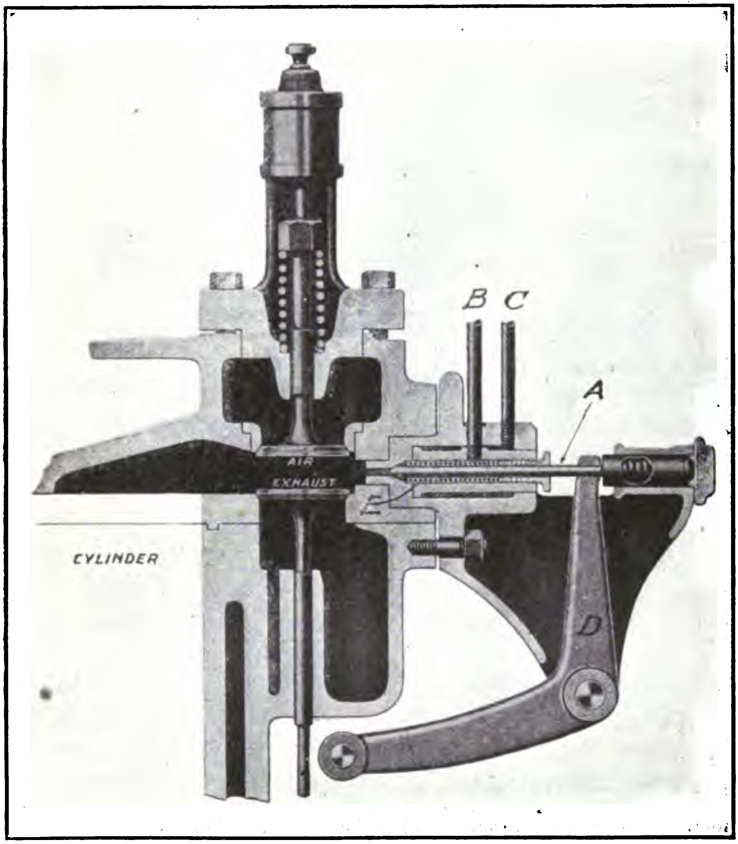


FIG. 86.—Valve Group, Diesel Engine.

Fuel is introduced through the pipe *B*, the amount being regulated by the governor for each cycle as stated above. Compressed air, which is previously cooled, enters at *C*, and the perforated

washers *E* serve to mix this air with the fuel. When the needle valve is opened the compressed air blows the fuel into the cylinder.

The exhaust valve is cam actuated from the same countershaft (Fig. 85) as is the fuel valve. In the engine shown here the air valve is an ordinary spring loaded valve which automatically opens on the suction stroke and closes on the compression stroke. In larger Diesel engines this valve is cam actuated in the same manner as the fuel and exhaust valves.

Limits of Power.—The power of the four cycle engine is limited by difficulties of dealing with the exhaust, unless auxiliary exhaust ports (similar to the two cycle exhaust ports described later) be introduced. Auxiliary exhaust ports have been applied to fast running four cycle engines to permit the escape of the high temperature gases before the cylinder head exhaust valve opens. This method of exhaust with both ports and valves decreases the mean effective pressure and decreases the efficiency of suction, since the ports are open at the beginning of the suction stroke and the quality of the charge is thus affected. The gain in weight and space occupied by the two cycle engine is not great, especially since the fuel consumption is about 10% greater in this type, but notwithstanding this, to obtain the maximum mean effective pressure per revolution the two cycle engine has been generally adopted for marine use.

The Two Cycle Diesel.

There are two general types of the two cycle Diesel engine in use in the U. S. Navy. They differ in the method of compressing and supplying the scavenging air. The Nurnberg engine compresses the scavenging air by means of a scavenger cylinder which is under and an integral part of the working cylinder and supplies this air through air valves in the cylinder head. The Sulzer engine compresses the scavenging air by a separate air compressor which is operated by the engine main shaft, and supplies this air through scavenger ports in the bottom of the cylinder side.

Each engine has an air compressor driven by the engine main

shaft to supply air for fuel injection, starting and reversing. In the following descriptions of these two engines care must be exercised to distinguish between the compressed air for scavenging and that for fuel injection. The former is maintained at only about 10 pounds pressure, and is supplied *differently* in the two engines. The latter, that for fuel injection and starting, is maintained at about 800 pounds pressure and is supplied in a similar manner in both engines.

The Nurnberg Engine.

The following description is that of a 450 horse-power Nurnberg Type Engine, as built by the New London Ship and Engine Co. for our submarines. The engine has six cylinders, with one two-stage air compressor at the forward end. The piston, Fig. 90, is in steps, the upper or smaller diameter being the working piston and the lower or larger diameter being the scavenger piston. The area of the annular part of the scavenger piston is about 1.4 times the area of the working piston, and maintains about 9 pounds pressure in the scavenger receiver. The space around the scavenger cylinder in the housing (5), Fig. 87, is used as a scavenger receiver, *F*.

The Cycle.—Assuming in Fig. 87 that the piston has just arrived at the top of its stroke, and consequently the cylinder is full of air compressed to about 500 pounds, then the cycle is as follows: On the down stroke the fuel valve shown on top of the cylinder at the left opens for about 1/10 of the stroke and fuel is injected during this period. The compressed air present in the cylinder is of sufficiently high temperature to ignite this fuel and combustion takes place during this period. After the piston has moved downward about 1/10 of the stroke the fuel valve closes, and expansion continues to nearly the end of the stroke. Near the bottom of the stroke the piston uncovers exhaust ports in the cylinder wall (not shown in the figure) which communicate with the exhaust pipe (1). Simultaneously the scavenger valve, shown on top of the cylinder at the right, opens and scavenger air at about 10 pounds pressure is introduced to the cylinder,

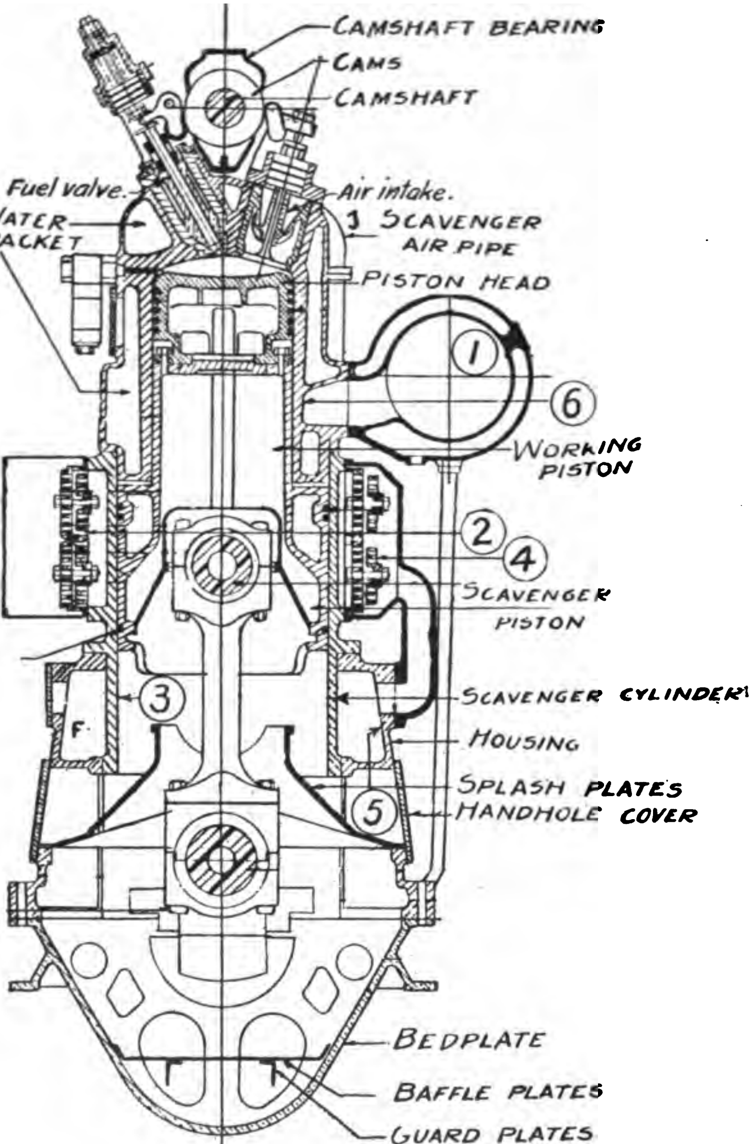


FIG. 87.—Cross Section, Nurnberg Engine.

blowing out the exhaust gases. This leaves the cylinder full of fresh air.

The piston, on its return stroke, first covers the exhaust ports (not shown) in the cylinder side, and then compresses the air present in the cylinder to about 500 pounds pressure. This completes the cycle.

Scavenging.—During the down stroke of the piston air is drawn through the scavenger suction valves (2), on the left of the cylinder, through ports (not shown) in the scavenger cylinder side. This is just below the working cylinder. On the up stroke this air is compressed to about 10 pounds pressure and discharged through the spring loaded scavenger discharge valves (4) to the annular casing formed by the housing (5). This is the scavenger receiver, *F*. The pressure of the scavenging air is regulated by the scavenger discharge valves.

The scavenger receiver, *F*, opens to all scavenger cylinders and merely acts as a reservoir, and no scavenger cylinder scavenges its own working cylinder. The scavenging air is led through a pipe, *J*, to the scavenger valve, and when that opens the air enters the cylinder and blows out the exhaust gases, the exhaust ports being uncovered during this period. As the scavenging is done with air and not with the fuel mixture as with the ordinary two cycle gasoline engine, complete scavenging and thus higher efficiencies can be obtained. Besides, the scavenger valve can be put where scavenging can best be effected. Also, while the actual volume of air is considerably less than the volume of the cylinder, the fact that this air is under 9 pounds pressure when the exhaust ports are closed gives this engine a volumetric efficiency very close to that of the four cycle engine, which has not a greater pressure at the same part of the stroke.

Fuel System.—Air for fuel injection is supplied by the air compressor, Fig. 89, to accumulators at about 800 pounds pressure. It acts at the fuel valve in a manner similar to that described under the four cycle Diesel engine.

There is a separate fuel-feed pump for each cylinder, which takes its motion from an eccentric on the forward end of the

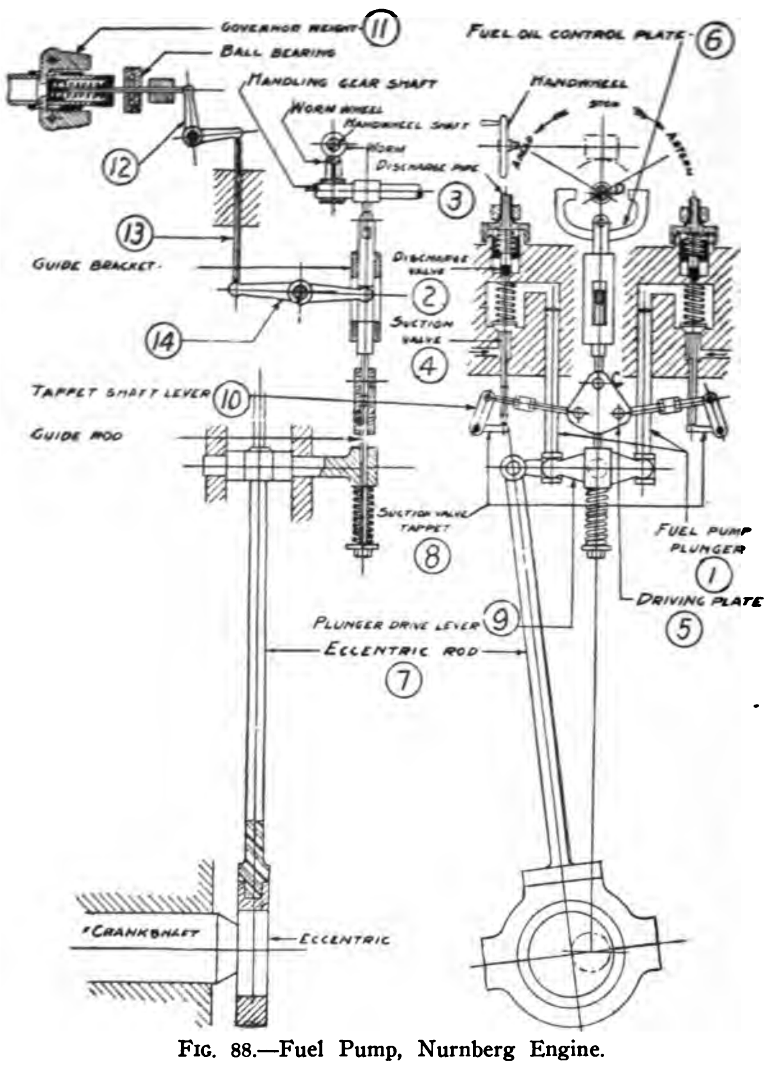


FIG. 88.—Fuel Pump, Nurnberg Engine.

crank shaft, Fig. 88. The pumps and valves are together at the forward end of the engine, and discharge through small copper pipes into the spray valves. The fuel control is ingenious. The plungers of the fuel feed pump (1), Fig. 88, run at a constant stroke and discharge through spring loaded valves (2), into the pipe line (3), to the spray valve. The suction valve (4) also acts as a regurgitating valve in connection with the plunger which, if open, allows the oil to return to the suction side of the pump. The amount of fuel at each revolution is governed by the length of time the regurgitating or suction valve is open. If the regurgitating or suction valve is open during the entire revolution of the engine no fuel will go into the engine. This is accomplished with a driving plate (5), which governs the stroke of the suction valve and in this manner regulates the opening. Fuel oil control plate (6) governs the position of the driving plate (5). As the fuel oil control plate revolves around *D* as a center, the center *C*, about which driving plate (5) oscillates, moves up or down. As the eccentric rod (7) moves up and down, the driving plate oscillates back and forth, making suction valve tappets (8) move up and down. At the same time plunger drive lever (9) oscillates and drives plungers (1) up and down a constant stroke. As the center *C* of the driving plate (5) moves down the arc through which tappet shaft lever (10) oscillates will move toward the center, suction valve tappet (8) will oscillate lower down, and the suction valve will be closed during a longer portion of the stroke. As *C* moves up, the tappet (8) will oscillate higher up and keep the suction valve open during a greater portion of the stroke. While suction valve (4) is open, the fuel will go back to the suction line. When it is closed the oil must go on through the discharge valve (2). Consequently, the amount of fuel discharged is governed by the length of time the suction valve is open, and this in turn is governed by the position of center *C* of the driving plate. The governing is done with the same device. That is, a ball governor (11) on the cam shaft is attached through levers (12, 13, 14) to fuel regulating device, and automatically regulates

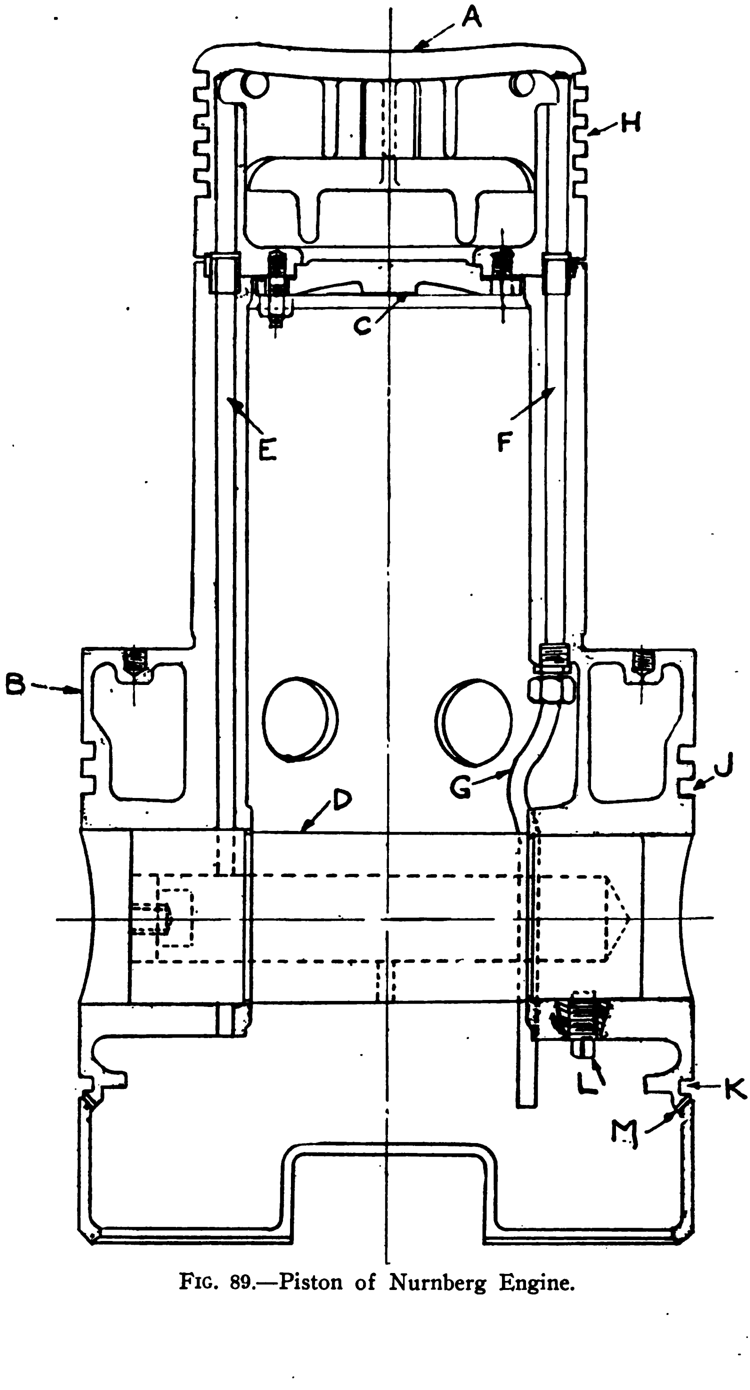


FIG. 89.—Piston of Nurnberg Engine.

the opening of the regurgitating valve in the same manner as the fuel control plate (6), and thus governs the engine.

Cooling and Lubrication.—The working and scavenger cylinders are of cast iron, but for lightness the housing and bedplates are of bronze. Fig. 87 shows that the scavenging and working cylinders are separate castings in this type of engine. The working cylinder (6) is water jacketed, as is the exhaust pipe (1). The air starting, spray, and scavenging valves are not jacketed.

The piston head *A*, Fig. 89, is oil cooled. The oil from the wrist pin *D* enters a hole *E* inside the piston, flows through the head, and out through another hole *F* on the opposite side of the piston, through a pipe *G* that is led clear of the wrist pin and into the crank pit. The piston is made in two sections. Lower section *B* includes the body of the working piston and the whole of the scavenging piston, while the upper section *A* is the piston head. This construction was adopted because of the trouble experienced with the core plugs in the top of the piston where the single casting type had been used. After a certain length of time these core plugs would come out, in spite of all precautions taken with their installation, and cause considerable damage. With the two-section type the holding-down bolts are in recesses in the side, and never come into contact with the hot gases, and, as the top has no holes of any description, there is now no trouble with core plugs loosening. The upper section is large enough to take all of the piston rings. The wrist pin *D* is secured in the scavenging piston and thus is not exposed to the heat of the working cylinder. This is a great advantage in that it is not difficult to keep the wrist pin bearings cool.

The circulating water is pumped through reciprocating pumps on the forward end of the engine geared down from the main shaft to 4/9 revolutions of the main engine. There is also a fuel pump for pumping fuel into the suction of the fuel feed pumps above described. This is run from the same crosshead from which are run the circulating pumps. All the handling gear pumps, etc., are on the forward end of the engine. The lubricating oil pump is also run from this crosshead. The cylinder lubri-

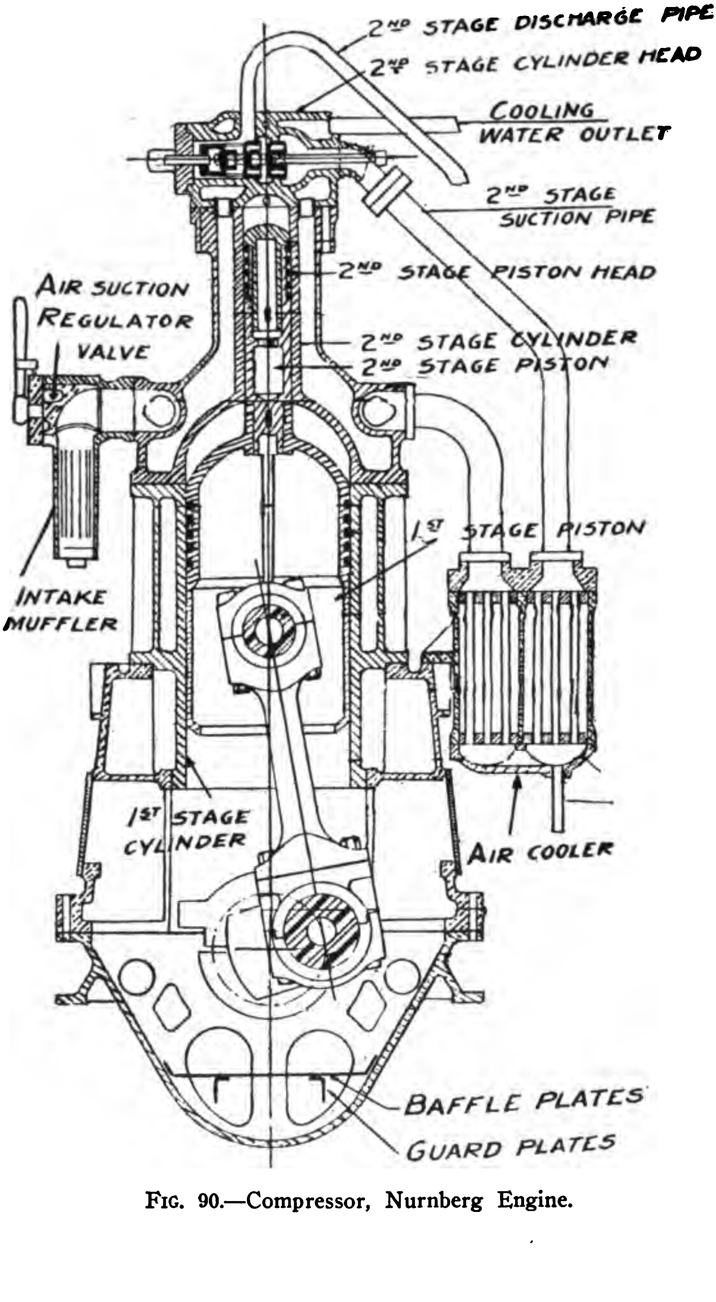


FIG. 90.—Compressor, Nurnberg Engine.

cating oil is forced under pressure by a special lubricating manifold run from the vertical cam shaft by spiral gearing on the after end of the engine.

Starting and Reversing.—The fuel, scavenger, and starting valves are all operated by levers from a cam shaft. This cam shaft is run from the main shaft by means of spiral gearing and vertical shaft. On the cam shaft are the spray cams, the scavenger cams, and the air starting cams. The reversing is accomplished with compressed air. The vertical shaft has a special coupling with a 30° blank. On reversing, the upper section remains stationary till the lower section has turned through 30° when all cams are then in position for motion in the opposite direction. For example: The spray valve begins to open when the crank is 2½° in advance of the top center and closes when the crank is 32½° beyond the top center. This gives an opening of the spray valve through 35°. Now by shifting the cam shaft back 30° by means of this clutch, the spray valve will begin to open 2½° on the opposite side and remain open beyond the stroke 32½° in the opposite direction, thus reversing the functions of the spray. The scavenging cams are reversed by the same action of the clutch and cam shaft.

The reversing is accomplished by separate cams and reversing valve, or air starting valve, which is the same for either direction. This air starting valve is in the cylinder head. It is not shown in Fig. 87.

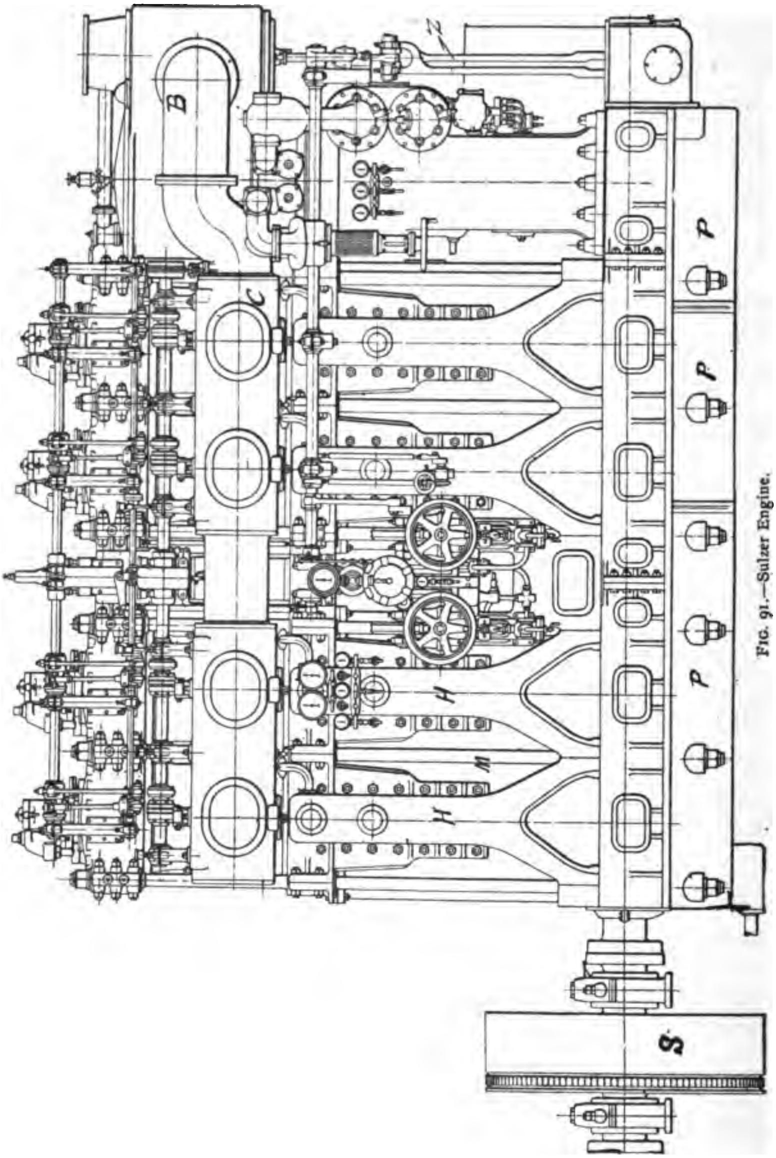


Fig. 91.—Sulzer Engine.

The Sulzer Engine.

The following is a description of the engines of the *Monte Penedo,* a 4,000-ton German steamer. Her engines were built by the Messrs. Sulzer Brothers, of Winterthur. They are each of 850 B. H. P. at 160 revolutions per minute, four cylinder, single acting, two cycle, directly reversible by compressed air. The four cylinders are coupled in pairs by the scavenger receivers and exhaust connections.

The Compressor.—On the forward end of each engine is a three stage air compressor, driven by a fifth crank on the main shaft. This compressor, Fig. 92, serves the double duty of supplying air at high pressure for fuel injection and starting, and at low pressure for scavenging. On the completion of the expansion or working stroke (at the pistons' lower dead center) the cylinders are scavenged and filled with pure air from this compressor.

In the air compressor, Fig. 92, the upper cylinder *A* is a double acting pump which supplies low pressure scavenging air. This air is distributed by valves driven by eccentrics at the end of the main shaft *Z,* Fig. 91. From the compressor the scavenging air travels through the pipe *B,* Figs. 91 and 92, to the receiver *C,* Figs. 91 and 93, thence to the main engine cylinder via the scavenging ports *D,* Fig. 93.

High pressure air at 955 pounds pressure, for fuel injection and starting, is also supplied by this compressor. From Fig. 92 it is seen that the first stage of the compressor *b* is placed directly below the scavenger pump. The pumps *c* and *d,* forming the second and third stages, respectively, are driven from the first stage piston rod by the rocking lever *f* and the links *g* and *e.* This high pressure air is stored in four groups of steel receivers or accumulators.

The compressors are water cooled and are provided with automatic valves, so that no special reversing gear is required.

Fuel System.—Oil is supplied from a tank in each engine room to the main fuel oil line. Fuel oil is supplied to all fuel valves of the engine by a fuel oil pump driven from the main

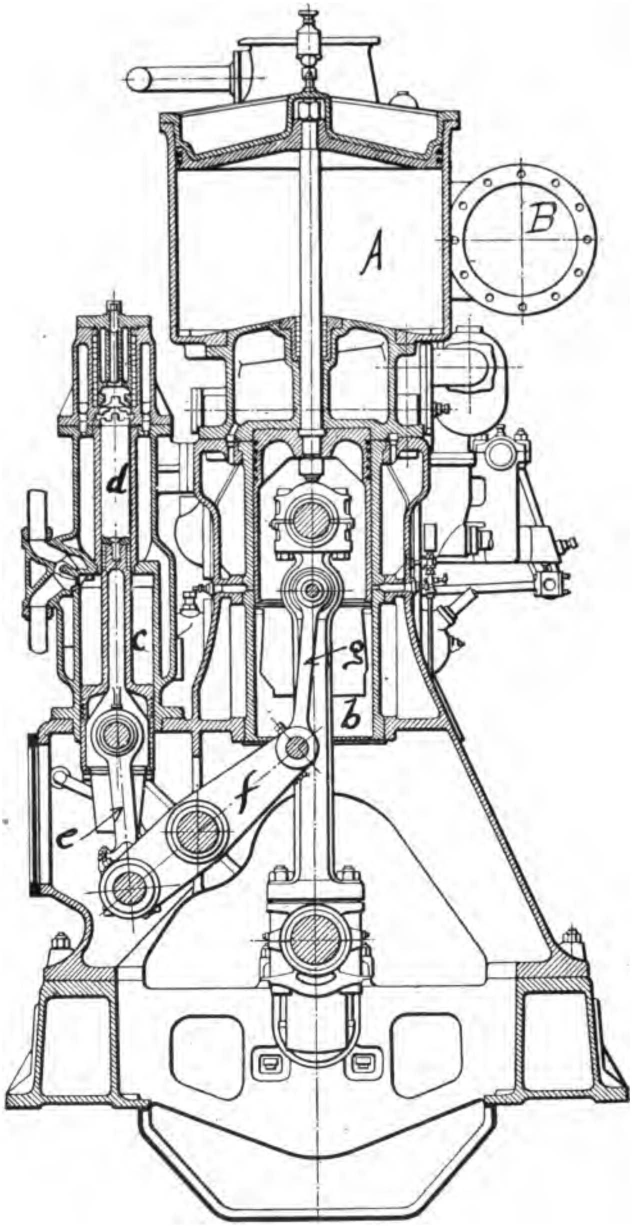


Fig. 92.—Compressor, Sulzer Engine.

engine by a rocking beam. A constant supply of oil is thus maintained at the fuel valve. The amount of fuel injected, hence the speed, is regulated by a governor which acts directly on the fuel valve. The method of fuel injection at the fuel valve is similar to that previously described.

Lubrication.—Each engine is fitted with forced lubrication, supplied by an oil circulation pump, driven by a rocking beam from the main engine, the installation comprising an oil cooler, with filters, pressure gages, controlling devices, and the necessary oil piping to every part requiring lubrication. The oil filters can be examined and cleaned while the engine is running. The oil is delivered to all the bearings and slide paths, and it collects in the base plate, whence it is drawn up by the pump. The working cylinders and air pumps are lubricated by small separate oil pumps.

Cooling.—The circulating water pump is driven by a rocking beam from the main engine. This supplies cooling water to the cylinder heads, and other stationary parts of the engine and compressor. A piston-head cooling pump, driven in a similar manner to the circulating pump, supplies cooling water to the hollow piston heads through a system of sliding tubes, one of which is shown at *F*, Fig. 93.

The engines are cooled by sea water when in the open sea. When, however, the ship is in harbor or in a roadstead, where the water available is charged with organic matter, they are cooled by a water circuit between the engines and the condenser, the latter being placed in circuit with the harbor or roadstead. The water piping is of copper of ample dimensions, provided with the necessary pressure gages and thermometers.

General.—The main engine cylinders are 18.5 inches in diameter, with a 26.8-inch stroke. Fig. 93 shows the construction of the cylinders with their water jackets. The casting forming the casing *G, G,* of the water jacket of each cylinder rests on the standards *H, H,* of the engine framing, and the barrel of the cylinder *J* is held by its upper end, so that it is free to expand downwards. The cylinder cover *K,* which is, of course, water

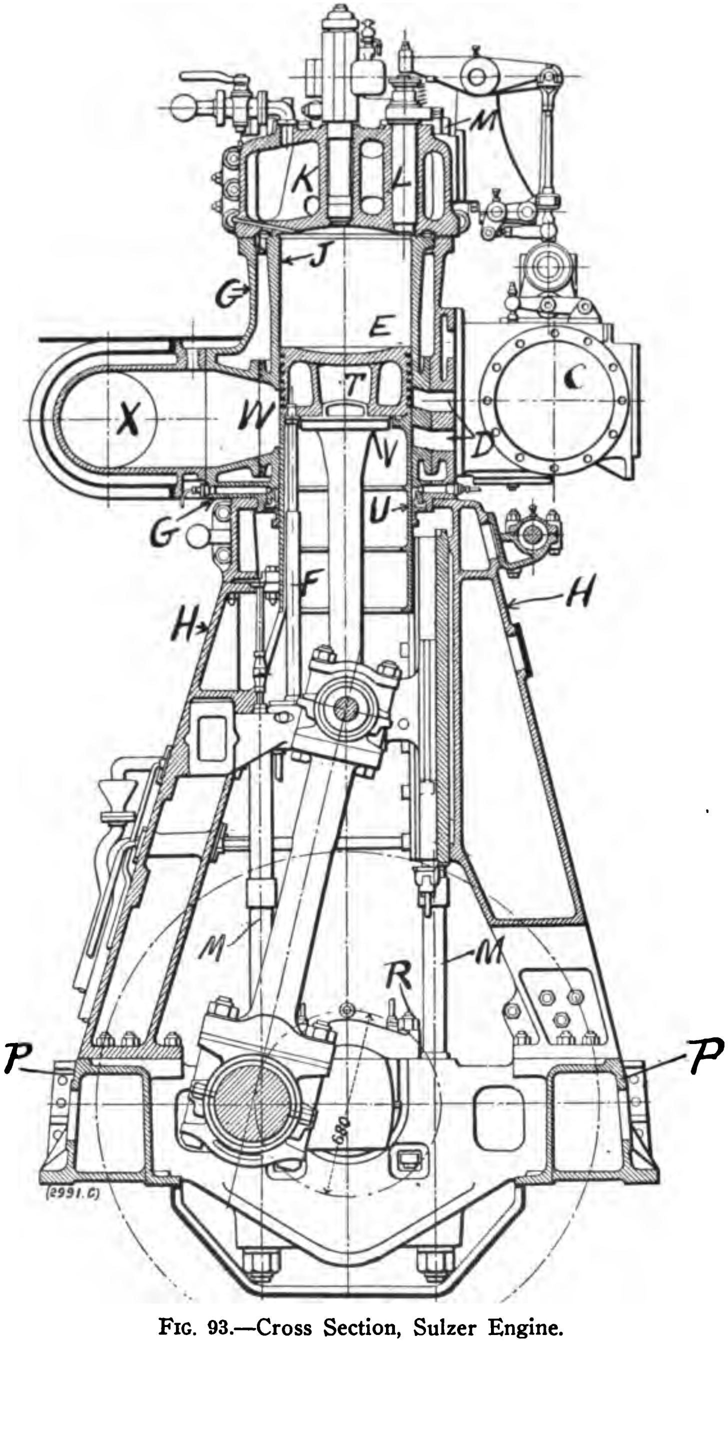


FIG. 93.—Cross Section, Sulzer Engine.

cooled, contains the fuel admission valve chamber *L,* and it is held in place by four large steel bolts, *M, M,* which pass down alongside the cylinder, through the framing standards, and also through the bed plate, as shown in Fig. 93, and on the left-hand side of the plan, Fig. 91. These bolts thus take all the tensional stresses, the standards of the engine framing and the castings of the water jackets being always in compression.

The **A**-frames, *H, H,* are of close grained cast iron, and are of very substantial proportions. They carry the cross head guides, as shown in Fig. 93. The base plate, *P, P,* is also of close grained cast iron, and is made in three parts, bolted together, as shown in Fig. 91. Two of these parts each carry the standards for a pair of cylinders, the other and forward part carrying the air compressing pumps. Bolted to the underside of the bed plate is a casting forming an oil catcher, into which drains all the surplus oil from the bearings, etc., this oil flowing thence to a tank for re-use after filtering and cooling.

The lower half of each crank shaft bearing is a steel shell lined with white metal, and made in cylindrical form, so that it can be readily rolled out without removing the shaft. The caps of the bearings are of cast iron, and are also lined with white metal. The bolts, *R,* holding down the caps are fixed as shown in Fig. 93, so that they are readily renewable if necessary. The crank shaft of each set of engines is in two parts, and has the cranks forged solid. The shafts are made of open hearth steel. On the first length of tail shaft coupled to the crank shaft is mounted a flywheel *S,* Fig. 91, weighing 8 tons.

The pistons are of cast iron, in two parts, the upper part *T* forming a closed chamber, through which the water for cooling is circulated by a system of sliding tubes *F.* The lower part of each piston is simply a trunk *U,* as shown in Fig. 93. The piston rods, which are all interchangeable, are of open hearth steel. Each rod is attached to its piston by a flange *V,* as shown in Fig. 93, and is bolted to the cross head. The connecting rods are also of open hearth steel, and their length is 4¼ times the crank

radius; the bearings are steel and bronze castings lined with white metal.

The air for scavenging enters the working cylinders through two horizontal rows of ports, *D, D,* in the cylinder walls shown on the right of the cylinder, Fig. 93; the openings of the lower row are controlled by the piston alone, whilst the upper row of openings is controlled by the scavenger valves and is eventually covered by the piston. Air to any desired quantity may be introduced into the cylinder through the upper row of ports after the piston has closed the lower scavenger openings.

The exhaust ports, *W*, are on the opposite side to the scavenger ports, also in the cylinder walls. The exhaust gases enter a water cooled exhaust pipe, *X*, leading to the muffler, from which they escape freely into the atmosphere. This method of scavenging gives excellent results, and from the point of view of simplicity of design and safety it forms a decided improvement on other methods, since, should a scavenger valve fail, it is impossible for a charge to escape into the exhaust pipe.

Auxiliaries.—Each engine drives direct by rocking beams a cooling water pump, a bilge pump, a sanitary pump, a piston head cooling pump, an oil fuel pump, and a pump for supplying the oil for the forced lubrication of the bearings. The bilge and sanitary pumps are both of the same capacity, and can deal with 20 tons of water per hour; both are of brass. Each engine has its own muffler and its own oil fuel tank, located in the engine-room.

A compressed air jacking gear is provided at the after end of each main engine. It gears into teeth cut into the periphery of the flywheel, Fig. 91.

There are two auxiliary 50 horse-power, three cylinder, four cycle, Sulzer-Diesel engines in addition to the above auxiliaries. One is coupled direct to a dynamo for lighting the ship, the other drives an air compressor for use in an emergency, such as failure of the normal air supply. When entering or leaving port, or at any time when an unusual amount of air is required for maneu-

vering, this compressor is run to maintain normal pressure at the accumulators.

Maneuvering Gear.—The maneuvering gear for controlling each main engine consists of two mechanisms, each operated by a compressed air engine through a worm drive. One of these engines serves to rotate the cam shaft through the desired angle with relation to the crank shaft, and to put over the scavenger pump valve rods into the required position for ahead or astern running. The other serves to operate the fuel and air starting valve gear, for starting, running, and stopping. All these operations can also be performed by hand in case of failure of the maneuvering engines for any cause whatsoever. The maneuvering engines are in the center of the main engine fronts, and so close together that both engines can be operated by one man.

The fuel valve and air starting valve of each cylinder are all operated by cams which are keyed on one cam shaft common to all four cylinders. For reversing, the engine is first run in the desired direction by means of compressed air supplied through the starting valves, the cam shaft being turned to the required angle in relation to the main shaft so that the lift of the fuel valves takes place at the right period of the cycle.

The action of the starting valves has to be reversible, so as to start the engine in the required direction. To do this there is provided both a forward and a backward running cam for each starting valve. A special gear is provided for connecting the cam rollers to or disconnecting them from the starting and the fuel cams. Eccentrics are fitted on the shaft in such a manner that the three following positions can be arrived at: (1) Both sets of cam rollers are out of action when the engine is at a standstill; (2) the starting valve cam rollers are thrown in, the fuel valve cams being out, which places the engine in the starting position; (3) the fuel valve cams are thrown in, the starting valve cams being thrown out, which places the engine in the running position. These positions are controlled by a cam disc which thus controls the engine when maneuvering. To reverse, the engine is first brought to a standstill; the cam shaft operating the valves is

then turned to the required position, ahead or astern, as the case may be; the air starting valves are thrown into gear, position 2, and the engine starts and runs on air; the fuel valves are thrown into gear and the air starting valves are thrown out of gear, position 3. The engine is now running on fuel in the desired direction.

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